Integrated Water Management Solutions in the Lurín Catchment, Lima, Peru

Supporting United Nations’ Sustainable Development Goal 6

Cover: Ururí reservoir in San Andrés de Tupicocha, Peru. Picture: C. D. León.

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Final report of the joint project TRUST "Sustainable, fair and environmentally sound drinking water supply for prosperous regions with water shortage: Developing solutions and planning tools for achieving the Sustainable Development Goals using the river catchments of the region Lima/Peru as an example", funded by the German Federal Ministry of Education and Research (BMBF) within the funding measure "Global Resource Water (GRoW)".

TRUST Report

Editorial

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TRUST Report

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Summary

English

With the **2030 Agenda for Sustainable Development**, the United Nations have established a catalog of 17 Sustainable Development Goals (SDGs) to achieve a better and more sustainable future for all by 2030. One important aspect, formulated as **Goal 6,** is **ensuring the availability and sustainable management of water and sanitation for all.** Achieving SDG 6 represents a challenge for planning, governance, and water management, especially in prosperous water-scarce regions, where water demand rises steadily and outgrows sustainable supply.

Over a 3,5-year period, the **joint project TRUST** (“Sustainable, fair and environmentally sound drinking water supply for prosperous regions with water shortage: Developing solutions and planning tools for achieving the Sustainable Development Goals using the river catchments of the region Lima/Peru as an example”) has developed **inter- and transdisciplinary concepts for drinking water use, safe wastewater disposal and water reuse to support achieving SDG 6 in water scarce regions, using the example of the catchment area of the Río Lurín, Peru.**

This report presents the approaches and results developed in the TRUST project. The approaches combine **natural, engineering and social science expertise from research and practice,** starting at the local level and scaled up to the level of catchment areas. They are structured along the domains of “water resources”, “water use” and “water management”. The domains are closely interlinked and support working towards the development of integrated water management concepts. Each of these domains begins with the **set-up of an information base,** followed by the **conduction of analysis and the development of concepts.** It concludes with the derivation of **lessons learned and recommendations** for each of the domains.

Generating a **sound multidisciplinary information base** is key for water resources planning and **conduction of analysis.** Installing a small number of monitoring stations at the right locations allows to get important insights on water quantity. Establishing and maintaining a **monitoring network for water quantity** is a challenging task in remote and mountainous areas, requiring long-term efforts and commitment. However, long time series are important to run hydrological models and even more if trends regarding climate change or land use change are to be considered in management decisions. Evaluating **water quality and associated risks** still requires conventional lab analyses, both physical-chemical and microbiological. Test kits that allow simple water analyses to be carried out by specifically trained local actors can provide an additional means to acquire water quality data. **Remote sensing techniques** can be applied for the classification of land use, the detection of land cover changes, and the estimation of soil moisture. They provide a basis for methodological solutions by establishing a land cover change detection approach with deep learning methods on multi-temporal satellite data.

A newly developed **decision support system** based on the WHO **Water Safety Plan concept (WSP)** enables the recording and evaluation of risks in the catchment area as well as the documentation of measures for risk control. As an online application with Web-GIS geodata processing, it is usable for users without own GIS access. The tool visualizes the results quickly, thereby supporting the communication about the aims of risk analysis and helping to achieve a common understanding of which information is relevant.

Regarding governance issues and conflict analysis, **stakeholder analysis** is important to obtain an overview on roles and relations. It allows to develop a **participation strategy** that identifies whom to involve during what project activity and in what intensity. Repeated field trips and interviews with key actors are required to achieve a full understanding and detailed overview of the of stakeholders' positions regarding the project's goals, and of the interrelations between stakeholder groups.

The newly developed **policy- and conflict analysis** allows identifying central (latent) water use related conflicts as well as developing and assessing possible integrated policy-solutions for an improved and sustainable water management. The approach makes diverging goals and policy alternatives of different water user groups explicit. It reveals how non-intended side-effects of policies affect the effectiveness of other policies and allows identifying consistent, synergetic and sustainable policy mixes.

For the development of **integrated concepts for water supply and sanitation**, an inter- and trans-disciplinary process, where scientists, water and sanitation engineers, social scientists as well as local actors and stakeholders collaborate closely, proves to be very helpful. **Participatory assessment** allows identifying the evaluation criteria that are relevant for local stakeholders and taking them into account in the further development of the concepts. Bringing actors from the upper and lower catchment together in joint **multi-stakeholder workshops** leads to more dialogue and fosters cooperation between catchment parts. Overall, the integrated approach allows to take the social-embeddedness of technological concepts into account and to **co-construct concepts together with local stakeholders.** Furthermore, involving stakeholders with different perspectives still requires ensuring the same level of information and knowledge. Stakeholders need to be enabled and empowered regularly to participate in the integrated planning processes – to this end, **capacity building** workshops are valuable. Using SDG 6 as a point of reference assured that our results are linkable to international debates and standards through the comparability of indicators.

Central conditions to **transfer** our **integrated approaches** include the active interest of stakeholders, a continuous and/or repeated collaboration between local actors, researchers and NGOs, as well as sufficient data, a common problem awareness, and comparable boundary conditions (regarding, e.g., hydrology, geochemistry, sociology, culture, education, urban water management, etc.). Local contexts, however, can be very specific, so the approaches need to be carefully contextualized.

Zusammenfassung

Deutsch

Mit der **Agenda 2030 für nachhaltige Entwicklung** haben die Vereinten Nationen einen Katalog von 17 Zielen für nachhaltige Entwicklung (Sustainable Development Goals, SDGs) aufgestellt, um bis 2030 eine bessere und nachhaltigere Zukunft für alle zu erreichen. Ein wichtiges Ziel ist im **SDG 6** zusammengefasst und betrifft die **Verfügbarkeit und nachhaltige Bewirtschaftung von Wasser und Sanitärversorgung für alle.** Das Erreichen des SDG 6 stellt insbesondere eine Herausforderung für Planung, Governance und Wasserwirtschaft in prosperierenden Wassermangelregionen dar, in denen der stetig steigende Wasserbedarf deutlich über der nachhaltigen Wassernutzung liegt.

Über einen Zeitraum von 3,5 Jahren wurden im **Verbundprojekt TRUST** („Trinkwasserversorgung in prosperierenden Wassermangelregionen nachhaltig, gerecht und ökologisch verträglich – Entwicklung von Lösungs- und Planungswerkzeugen zur Erreichung der nachhaltigen Entwicklungsziele am Beispiel des Wassereinzugsgebiets der Region Lima/Peru.“) am Beispiel des **Einzugsgebiets des Río Lurín** in Peru **inter- und transdisziplinäre Konzepte zur Trinkwassernutzung, sicheren Abwasserentsorgung und Wasserwiederverwendung** entwickelt, um zum **Erreichen des SDG 6 in wasserarmen Regionen** beizutragen.

Dieser Bericht stellt die im TRUST-Projekt entwickelten Ansätze und Ergebnisse vor. Die Ansätze kombinieren **natur-, ingenieur- und sozialwissenschaftliches Fachwissen aus Forschung und Praxis**, beginnend auf lokaler Ebene und skalierbar bis auf die Ebene von Einzugsgebieten. Die Ansätze orientieren sich an den Bereichen „Wasserressourcen“, „Wassernutzung“ und „Wassermanagement“, wobei diese Bereiche eng miteinander verknüpft sind und somit die Entwicklung integrierter Wassermanagementkonzepte erlauben. In jedem Bereich wird zunächst **eine Informationsbasis aufgebaut**, woran die **Durchführung von Analysen sowie die Konzeptentwicklung** anknüpft. Schließlich werden für jeden Bereich die zentralen ***Lessons Learned*** und **Empfehlungen** abgeleitet.

Es zeigt sich, dass eine **solide multidisziplinäre Informationsbasis** eine Schlüsselrolle für die Wasserressourcenplanung und die **Durchführung der Analysen** spielt. Bereits die Installation weniger Messstationen an den richtigen Stellen ermöglicht es, wichtige Erkenntnisse über die Wassermengen zu gewinnen. Der Aufbau und die Instandhaltung eines **Messnetzes zur Bestimmung der Wassermengen** in abgelegenen Bergregionen ist eine anspruchsvolle Aufgabe, die langfristige Anstrengungen und Einsatz erfordert. Lange Zeitreihen sind jedoch umso wichtiger, um hydrologische Modellierung zu betreiben und Trends in Bezug auf den Klimawandel oder Landnutzungsänderungen in Managemententscheidungen zu berücksichtigen. Die Auswertung der **Wasserqualität und der damit verbundenen Risiken** erfordert nach wie vor konventionelle, physikalisch-chemische und mikrobiologische Laboranalysen. Testkits, mit denen speziell geschulte lokale Akteure einfache Wasseranalysen durchführen können, bieten eine zusätzliche Möglichkeit zur Erfassung von Wasserqualitätsdaten. **Fernerkundungstechniken** können eingesetzt werden, um die Landnutzung zu klassifizieren, Änderungen der Landbedeckung zu erkennen und die Bodenfeuchte abzuschätzen. Sie liefern eine Grundlage für methodische Lösungen, indem sie einen Ansatz zur Erkennung von Veränderungen der Landbedeckung mit Deep Learning Methoden auf multitemporalen Satellitendaten kombinieren.

Ein neu entwickeltes **Entscheidungsunterstützungssystem** auf Basis des WHO **Water Safety Plan-Konzepts (WSP)** ermöglicht die Erfassung und Bewertung von Risiken im Einzugsgebiet

sowie die Dokumentation von Maßnahmen zur Risikokontrolle. Als Online-Anwendung mit Web-GIS-Geodatenaufbereitung ist es auch für Anwender ohne eigenen GIS-Zugang nutzbar. Das Tool visualisiert die Ergebnisse und unterstützt damit die Kommunikation über die Ziele der Risikoanalyse und hilft, ein gemeinsames Verständnis über relevante Informationen zu schaffen.

Im Hinblick auf Governance-Themen und Konfliktanalyse ist die **Stakeholder-Analyse** wichtig, um einen Überblick über Rollen und Beziehungen zu erhalten. Sie ermöglicht zudem, eine **Partizipationsstrategie** zu entwickeln, die festlegt, welche Akteure in welcher Projektphase zu welchem Grad einbezogen werden sollen. Wiederholte Feldaufenthalte und Interviews mit Schlüsselakteuren sind erforderlich, um ein umfassendes Verständnis und einen detaillierten Überblick über die Haltung der Stakeholder hinsichtlich der Projektziele sowie der Beziehungen zwischen den Stakeholdergruppen zu gewinnen.

Die neu entwickelte **Politik- und Konfliktanalyse** ermöglicht, zentrale (latente) Wassernutzungskonflikte zu identifizieren und mögliche integrierte Politiklösungen für ein verbessertes und nachhaltiges Wassermanagement zu entwickeln und zu bewerten. Der Ansatz macht divergierende Ziele und Policy-Alternativen der verschiedenen Wassernutzergruppen explizit. Er deckt nicht-intendierte Nebeneffekte von Policies (Maßnahmen und Instrumente) auf die Effektivität anderer Policies auf und ermöglicht, konsistente, synergetische und nachhaltige Policy-Mixes zu identifizieren.

Für die Entwicklung von **integrierten Konzepten für die Wasserver- und Abwasserentsorgung** erweist sich ein inter- und transdisziplinärer Ansatz als sehr hilfreich, bei dem Forscherinnen und Forscher aus Naturwissenschaften, Wasser- und Abwassertechnik sowie Sozialwissenschaften eng mit lokalen Akteuren und Interessengruppen zusammenarbeiten. Mithilfe von **partizipativen Bewertungsformaten** werden die für lokale Akteure relevanten Entscheidungskriterien identifiziert und fließen in die weitere Konzeptentwicklung ein. Gemeinsame **Multi-Stakeholder-Workshops** bringen die Akteure aus dem oberen und unteren Einzugsgebiet zusammen, was den Dialog und die Zusammenarbeit im Einzugsgebiet fördert. Insgesamt ermöglicht es der integrierte Ansatz, technologische Konzepte sozial einzubetten und **die Konzepte gemeinsam mit lokalen Akteuren zu entwickeln.** Um die diversen Stakeholder mit ihren unterschiedlichen Perspektiven erfolgreich zu beteiligen, ist es erforderlich, einen gleichen Informations- und Wissensstand sicherzustellen. Die Stakeholder sollten unterstützt und befähigt werden, sich regelmäßig an den integrierten Planungsprozessen zu beteiligen - zu diesem Zweck sind auch Veranstaltungen zum Capacity Building hilfreich. Die Verwendung von SDG 6 als Bezugspunkt stellte sicher, dass unsere Ergebnisse durch die Vergleichbarkeit der Indikatoren mit internationalen Debatten und Standards anschlussfähig sind.

Zentrale Voraussetzungen für die **Übertragbarkeit** unserer **integrierten Ansätze** sind unter anderem die Mitarbeit aktiver Stakeholder, die kontinuierliche und/oder wiederholte Zusammenarbeit von lokalen Akteuren, Forschern und NGOs, eine ausreichende Datengrundlage, ein gemeinsames Problembewusstsein sowie vergleichbarer Randbedingungen (z. B. hinsichtlich Hydrologie, Geochemie, Soziologie, Kultur, Bildung, Siedlungswasserwirtschaft, usw.). Lokale Kontexte können jedoch äußerst spezifisch sein, so dass die Ansätze sorgfältig auf die lokalen Bedingungen abgestimmt werden müssen.

Resumen

Español

Con la **Agenda 2030 para el Desarrollo Sostenible**, las Naciones Unidas han establecido un catálogo de 17 Objetivos de Desarrollo Sostenible (ODS) para lograr un futuro mejor y más sostenible para todos en 2030. Un aspecto importante, formulado como **Objetivo 6**, es **garantizar la disponibilidad y la gestión sostenible del agua y el saneamiento para todos.** La consecución del ODS 6 representa un reto para la planificación, la gobernanza y la gestión del agua, especialmente en las regiones prósperas con escasez de agua, donde la demanda de agua aumenta constantemente y supera el suministro sostenible.

A lo largo de un periodo de 3,5 años, el **proyecto TRUST** („Suministro de agua potable sostenible, equitativo y ecológico en regiones prósperas con déficit hídrico – Desarrollo de soluciones y herramientas de planificación para lograr los Objetivos de Desarrollo Sostenible, utilizando el ejemplo de la cuenca hidrográfica de la región Lima / Perú“) ha desarrollado **conceptos inter- y transdisciplinarios para el uso del agua potable, la eliminación segura de las aguas residuales y la reutilización del agua para apoyar la consecución del ODS 6 en regiones con escasez de agua,** utilizando el ejemplo de la **cuenca del Río Lurín, Perú**.

Este informe presenta los enfoques y resultados desarrollados en el proyecto TRUST. Los enfoques combinan los **conocimientos de las ciencias naturales, la ingeniería y las ciencias sociales procedentes de la investigación y la práctica**, comenzando en el ámbito local y ampliando hasta el nivel de las cuencas hidrográficas. Están estructurados en los ámbitos de „recursos hídricos“, „uso del agua“ y „gestión del agua“. Estos ámbitos están estrechamente interrelacionados y permiten trabajar en el desarrollo de conceptos de gestión integrada del agua. Cada uno de estos ámbitos comienza con la **creación de una base de información**, seguida de la **realización de análisis y el desarrollo de conceptos**. Concluye con la derivación de **lecciones aprendidas y recomendaciones** para cada uno de los dominios.

La generación de una **sólida base de información multidisciplinar** es fundamental para la planificación de los recursos hídricos y la **realización de análisis**. La instalación de un pequeño número de estaciones de control en los lugares adecuados permite obtener información importante sobre la cantidad de agua. Establecer y mantener una **red de monitoreo de la cantidad de agua** es una tarea difícil en zonas remotas y montañosas, que requiere esfuerzos y compromisos a largo plazo. Sin embargo, las series temporales largas son importantes para ejecutar modelos hidrológicos y aún más si las tendencias relacionadas con el cambio climático o el cambio en el uso de la tierra deben tenerse en cuenta en las decisiones de gestión. La evaluación de **la calidad del agua y los riesgos asociados** sigue requiriendo análisis de laboratorio convencionales, tanto físico-químicos como microbiológicos. Los kits de pruebas que permiten la realización de análisis sencillos del agua por parte de actores locales con formación específica pueden proporcionar un medio adicional para adquirir datos sobre la calidad del agua. Las **técnicas de teledetección** pueden aplicarse para la clasificación de los usos del suelo, la detección de cambios en la cubierta vegetal y la estimación de la humedad del suelo. Proporcionan una base para soluciones metodológicas estableciendo un enfoque de detección de cambios en la cobertura del suelo con métodos de aprendizaje profundo sobre datos satelitales multitemporales.

Español

Un **sistema de apoyo a la toma de decisiones** recientemente desarrollado, basado en el concepto de **Plan de Seguridad del Agua (PSA)** de la OMS, permite registrar y evaluar los riesgos en la zona de captación, así como documentar las medidas de control de riesgos. Al ser una aplicación en línea con procesamiento de geodatos Web- GIS, puede ser utilizada por usuarios sin acceso propio a los SIG. La herramienta visualiza rápidamente los resultados, apoyando así la comunicación sobre los objetivos del análisis de riesgos y ayudando a lograr una comprensión común de qué información es relevante.

En cuanto a los temas de gobernanza y el análisis de conflictos, el **análisis de las partes interesadas** es importante para obtener una visión general de los roles y las relaciones. Permite desarrollar una **estrategia de participación** que identifique a quién hay que involucrar durante qué actividad del proyecto y en qué intensidad. Es necesario realizar repetidos viajes de campo y entrevistas con los actores clave para lograr una comprensión completa y una visión detallada de las posiciones de las partes interesadas con respecto a los objetivos del proyecto, y de las interrelaciones entre los grupos interesados.

El nuevo **análisis de políticas y conflictos** permite identificar conflictos centrales (latentes) relacionados con el uso del agua, así como desarrollar y evaluar posibles soluciones políticas integradas para una gestión del agua mejorada y sostenible. El enfoque hace explícitos los objetivos divergentes y las alternativas políticas de los diferentes grupos de usuarios del agua. Revela cómo los efectos secundarios no intencionados de las políticas afectan a la eficacia de otras políticas y permite identificar combinaciones de políticas coherentes, sinérgicas y sostenibles.

Para el desarrollo de **conceptos integrados de abastecimiento de agua y saneamiento**, resulta muy útil un proceso inter y transdisciplinar en el que colaboren estrechamente científicos, ingenieros especializados en agua y saneamiento, científicos sociales y actores y partes interesadas locales. La **evaluación participativa** permite identificar los criterios de evaluación que son relevantes para los actores locales y tenerlos en cuenta en el desarrollo posterior de los conceptos. Reunir a los actores de la cuenca alta y baja en **talleres** conjuntos de **múltiples partes interesadas** conduce a un mayor diálogo y fomenta la cooperación entre las partes de la cuenca. En general, el enfoque integrado permite tener en cuenta la integración social de los conceptos tecnológicos y **construir los conceptos junto con las partes interesadas locales.** Además, la participación de las partes interesadas con diferentes perspectivas sigue exigiendo que se garantice el mismo nivel de información y conocimiento. Es necesario capacitar y empoderar a las partes interesadas para que participen regularmente en los procesos de planificación integrada; para ello, son valiosos los talleres de **desarrollo de capacidades**. El uso del ODS 6 como punto de referencia garantizó que nuestros resultados fueran vinculables a los debates y normas internacionales gracias a la comparabilidad de los indicadores.

Las condiciones centrales para **transferir** nuestros **enfoques integrados** incluyen el interés activo de las partes interesadas, una colaboración continua y/o repetida entre los actores locales, los investigadores y las ONG, así como datos suficientes, una conciencia común del problema y condiciones de contorno comparables (en relación, por ejemplo, con la hidrología, la geoquímica, la sociología, la cultura, la educación, la gestión del agua urbana, etc.). Sin embargo, los contextos locales pueden ser muy específicos, por lo que los enfoques deben ser cuidadosamente contextualizados.

1. Introduction

Christian D. León


Picture: C. D. León

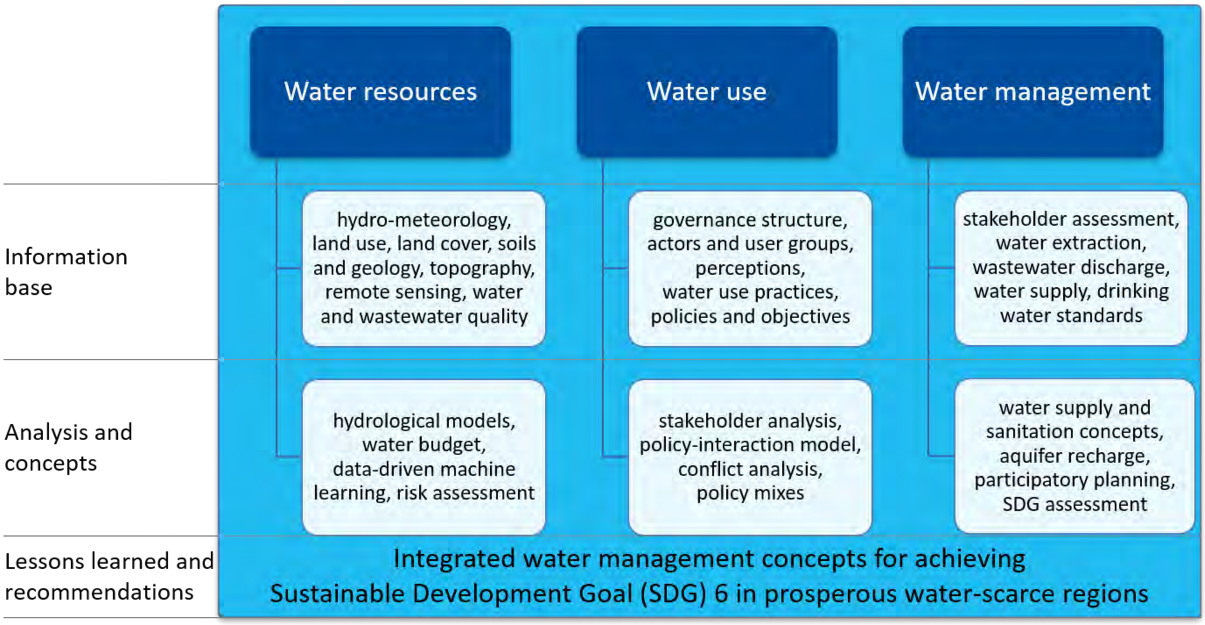
Many regions of the world are characterised by natural water scarcity. Their ecosystems are adapted to this water shortage and specifically adapted animal and plant species have settled here. Similarly, humans have been adapting their farming and agricultural methods to cope with water shortage. Only by building reservoirs, wells, irrigation systems and diverting water from one catchment area to the other, men ensured that stronger economic development became possible in these water-scarce regions than originally thought. In the last decades, this development, accompanied by population growth, has increased the pressure on water resources. The consequences are severely stressed or disappearing water-bound local ecosystems on the one hand and lack of access to sufficient drinking water to meet human needs on the other hand.

Ensuring economic development and the protection of ecosystems at the same time is a challenge, which many regions of the world are facing today. This holds especially true for those located in water scarce areas. In addition, there are further goals to be accomplished, such as reducing poverty and securing energy supplies. With the adoption of the 2030 Agenda for Sustainable Development, the United Nations have established a catalogue of 17 goals aimed to eradicate poverty in all its forms and dimensions worldwide (UN, 2015). A central aspect is the "availability and sustainable management of water and sanitation for all", which is formulated as goal No. 6 of the UN Sustainable Development Goals (SDGs) and is to be achieved by 2030. This goal, which is specified by six targets, addresses both people's needs for equitable access to safe drinking water and sanitation, and the protection of water-related ecosystems (Krauss et al., 2019). Achieving the SDGs in the water sector represents a challenge to planning, governance and water management, especially in prosperous water-scarce regions, where water demand is rising steadily.

The research project TRUST was entitled „Sustainable, fair and environmentally sound drinking water supply for prosperous regions with water shortage: Developing solutions and planning tools for achieving the Sustainable Development Goals using the river catchments of the region Lima/ Peru as an example" (León et al., 2019). The project was funded over a 3 ½ -year period by the German Federal Ministry of Education and Research (BMBF) within the funding measure "Water as a global Resource (GRoW)". GRoW aimed to support achieving SDG 6 by funding twelve research projects in the thematic fields of "global water resources", "global water demand" and "good governance in the water sector". Using the example of the catchment area of the Río Lurín, Peru, the TRUST project demonstrated how interdisciplinary approaches can contribute to meet water management challenges and contribute to SDG 6 "Ensure availability and sustainable management of water and sanitation for all" in prosperous regions with water scarcity. In addition to the Río Lurín catchment in Peru, the Klingenberg catchment area in the Federal State of Saxony, Germany, served as a test area for the application of specific tools and procedures.

The Río Lurín catchment area (1 670 km^2) is one of three water catchment areas relevant for the water supply of Lima, the capital of Peru. It is an area combining typical characteristics of prosperous regions of the world, where fast growing urban centres and competing domestic, agricultural and industrial use of water resources are exacerbating water shortage. Although the contribution of the Río Lurín to the total water resources of the three catchment areas is low (11 % of total surface water and 10 % of groundwater resources), the Río Lurín is becoming increasingly important for the water supply in the lower catchment area. However, its increasing importance poses major challenges to water governance due to a weak institutional framework in combination with an insufficient data basis.

The research in TRUST was structured along the domains of “water resources”, “water use” and “water management” (see Figure 1.1). The domains are closely interlinked and thus this clear structure supported the work towards the development of integrated water management concepts. The objective of the first domain (water resources) is to characterize the catchment and to assess the availability and quality of water resources in the catchment area. The second domain (water use) aims at describing the different water users, assessing their respective water demand and analyzing potential conflicts. The third domain (water management) describes policy options as a function of available water resources and water demand. The work in each of these domains began with the set-up of an information base, followed by the conduction of analysis and development of concepts. In this context, the TRUST project developed concepts for drinking water use, safe wastewater disposal and water reuse in close cooperation with local actors and national authorities.



» ***Figure 1.1:*** *Structure of the TRUST research approach along the three domains “water resources”, “water use” and “water management”.*

This report presents the results and findings of the TRUST project. Inter- and transdisciplinary approaches are shown that combine natural, engineering and social science expertise from research and practice. The approaches start at the local level and can be scaled up to the level of catchment areas.

The TRUST report is intended as a manual to help decision-makers and people professionally engaged in water management to develop and implement locally adapted solutions for sustainable water management.

The chapters are organised according to the structure shown in Figure 1.1. Chapter 2 provides an overview of the information base and the different data collected during the project. The analysis and concepts for the Lurín catchment are described in Chapter 3 and divided between the upper part (Chapter 4) and the lower part (Chapter 5). Chapter 6 summarizes the main findings and recommendations regarding results, lessons learned and transfer of the TRUST approach.

Zooming in: Perú, Lima, Lurín

Jan Wienhöfer

Perú with an area of about 1.3 million km^2 is the third largest country in South America, and covers three major biomes: the arid pacific coastal region in the west (12 %), the highlands of the Andes mountains (28 %), and the tropical rainforest of the Amazon basin in the east (60 %).

Renewable water resources sum up to about 1 880 × 10^9 m^3/year, or 59 782 m^3 per capita and year (Aquastat, 2017), which makes Perú the country with the eighth largest renewable water resources worldwide. These water resources, however, are mainly (97.3 %) available in the Atlantic drainage divide east of the Andes, while the more populated Pacific divide west of the Andes receives significant less rainfall, and only has a share of 2.2 % of the nation's water resources (the remaining 0.5 % are found in the Titicaca divide).

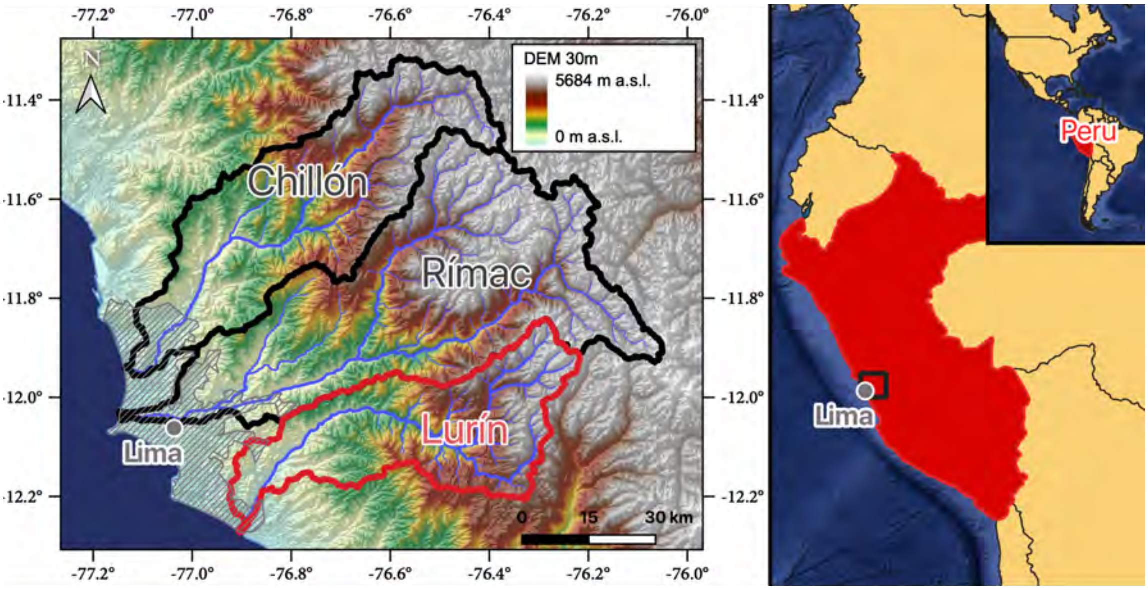
Population estimates for Perú surpass 33 million people in 2020 (UNDESA, 2019), of which two-thirds live in the arid coastal region, mainly in fast-growing cities like the nation's capital Lima with 10 million inhabitants (INEI, 2018).

Generally, the access to drinking water in urban areas is higher than in rural areas: In 2020, 23.7 % of the rural population had no access to the public drinking water network, in contrast to 5.2 % of the population in urban areas of Peru (INEI, 2020). This difference is even bigger regarding the connection to the sewage system: 80.5 % of the population in rural areas and 10.3 % of the population in urban areas had no access to a public sewage system (INEI, 2020). Community-managed organizations such as the Juntas Administradoras de Servicios de Saneamiento (JASS) are managing most of the water services in rural areas, while (public, private or public-private) companies and local governments are supplying the majority of urban areas (Calzada et al., 2017).

Lima, situated in the coastal desert, receives less than 10 mm per year of rainfall and thus depends on the water brought from the Andes by three river catchments, namely Chillón, Rímac and Lurín, often taken together as CHIRILU (Figure 1.2). The catchments are typical for the Peruvian coast, in that they extend in an elongated shape from the sea to the top of the Andes at 4 700 to 5 500 m asl, featuring deep valleys and a steep topography. Water from the Mantaro catchment east of the watershed divide (belonging to the Amazon basin) is brought through tunnels into the Rímac catchment to augment the available water resources for Lima. Water availability in CHIRILU reduces to 125 m^3 per capita and year, a tremendous difference to the national average of 64 000 m^3 per capita and year (Aquafondo, 2016).

Water resources in the CHIRILU catchment mainly come from surface waters (83 %), of which the most is taken from the Río Rímac (69 %), and to a lesser extent from the Río Chillón (20 %) and Río Lurín (11 %). Groundwater sources contribute to 17 % to the water supply, of which 90 % are taken from the Chillón-Rímac aquifer and 10 % from the Lurín aquifer (Aquafondo, 2016).

The Río Lurín catchment is located south of Lima and covers an area of 1 670 km^2 (Figure 1.2). The Lurín is about 111 km long und has its source in the Andes at about 5 300 m asl. Although the contribution of the Río Lurín to the total water resources of the three catchment areas is low (11 % of total surface water and 10 % of groundwater resources), it is becoming increasingly important for the water supply, not only for the population of Lima, but also for industry and agriculture in the lower catchment area. This is of particular importance for Lima, where the population is continuously growing. In the search for water sources for the increasing water demand of population and industry, the Río Lurín is therefore gaining more and more importance.



» ***Figure 1.2:*** *Location of the Lurín catchment near Lima, Peru.*

2. Data and Assessment Tools

Organizing author: Sina Keller

In this chapter, we introduce different types of data that researchers of various disciplines measured and collected within the TRUST project at different locations in Peru and Germany.

First, we provide a brief overview of the different data types (Table 2.1), followed by a short description of the data storage and the possibility to access selected data via a GIS portal. To combine our heterogeneous data, we structure the data according to the research discipline responsible for the acquisition, the study region to which the data relate, and briefly describe the data source and the specification. In the subsequent sections, selected examples of the listed data types are presented in more detail.

Section 2.2 gives an overview of the hydro-meteorological monitoring of the Chillón-Rímac-Lurín (CHIRILU) catchment in Peru and illustrates some details of the acquisition of hydrological and meteorological data in the Lurín catchment. In addition to hydro-meteorological data, remote sensing data were acquired as a basis for data-driven machine learning (ML) approaches aiming at the estimation of different physical parameters such as soil moisture or chlorophyll a concentration (see Section 2.3). To develop ML approaches for the estimation of such parameters, the respective reference data are crucial and are exemplarily described. Furthermore, we collected information on stakeholders and water policies to design participatory approaches for conflict transformation (see Section 2.4). The last part of this chapter (Section 2.5) deals with the monitoring of water quality parameters in general, and gives an example of monitoring of microbiological and physicochemical water quality at Klingenberg Reservoir in Saxony, Germany.

2.1 Overview of the TRUST Data and Data Management

Table 2.1 summarizes the different data that we measured or collected in the context of the TRUST project. The data cover several areas: the Lurín catchment in Peru (Lurín) and its adjacent catchments (Chillón, Rímac, Lurín - CHIRILU), the district of San Andrés de Tupicocha within the upper Lurín catchment, and the catchment area of the Klingenberg reservoir in Saxony (Germany).

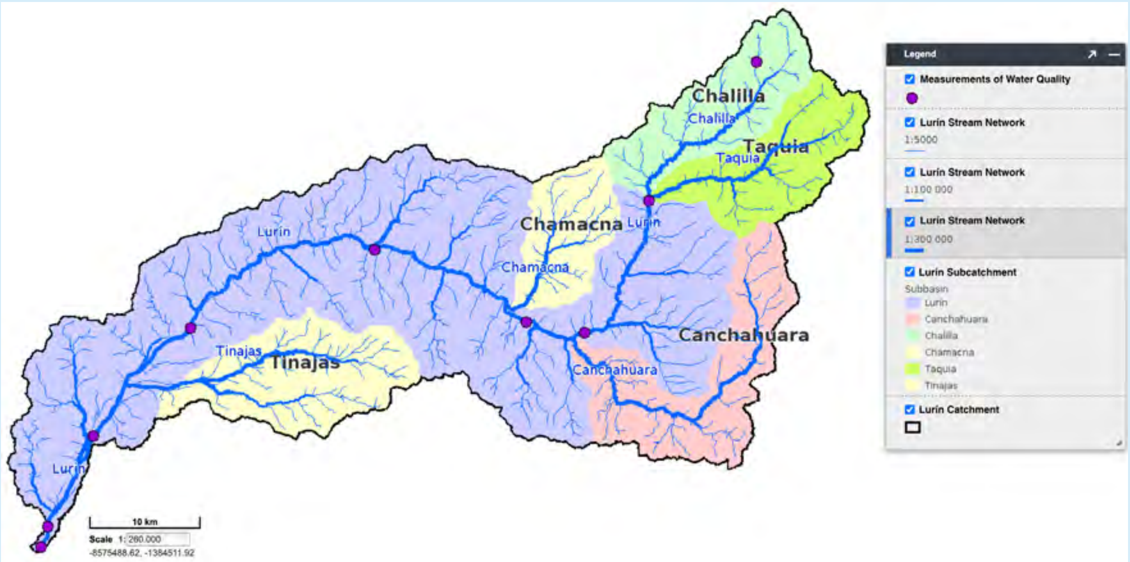
» *Table 2.1:*
Overview of the data measured and collected within the TRUST project. The data are related to the Lurín catchment in Peru (Lurín), the district of San Andrés de Tupicocha in the Lurín catchment, the CHIRILU catchments in Peru, or the catchment area of the Klingenberg reservoir in Saxony (Germany). For full designations, see list of abbreviations in the Annex.

DATA TYPE ***STUDY REGION***	**SPECIFICATION**	**SOURCE**	**REFERENCE**
Actors & governance structure *Lurín (PER)*	• Actor types • Networks • Positions and influence	• Desk research • Stakeholder interviews • Stakeholder mapping	Chapter 3.3, 4.2
Administrative & demography *Lurín (PER)*	• Administrative units • Cities, urban and rural regions • Population	• OSM • INEI (PER)	Chapter 3.1, 4.1, 5.1
Hydro-meteorological *CHIRILU (PER)*	• Air pressure & temperature • Precipitation • Relative humidity • Soil moisture • Solar radiation	• Own measurements • SEDAPAL (PER) • SENAMHI (PER)	Chapter 2.2, 2.3, 3.2
Land use & land cover *Lurín (PER) & Klingenberg (DEU)*	• Classes of land cover & land use including vegetation & agriculture	• GeoSN (DEU) • UNALM (PER) • MINAM (PER)	Chapter 2.3, 3.2
Pedological & geological *Lurín (PER) & Klingenberg (DEU)*	• Rock type • Soil infiltration rate • Soil texture • Soil type	• Own measurements • INGEMMET (PER) • LfULG (DEU)	Chapter 2.3
Perceptions & practices *Tupicocha (PER)*	• People`s perceptions, attitudes and practices regarding water use	• Focus group workshop • Transect walk	Chapter 4.3
Water policies and objectives *Lurín (PER)*	• Central water objectives and alternative policies in the upper and lower catchment	• Desk research • Workshops with local experts and stake holders	Chapter 2.4, 3.4
Remote sensing *Lurín (PER),Klingenberg (DEU) & inland waters around Karlsruhe (DEU)*	• Hyperspectral image data • Multispectral satellite data • Hyperspectral spectrometer data	• Own measurements • ESA Sentinel-2 mission	Chapter 2.3

DATA TYPE *STUDY REGION*	SPECIFICATION	SOURCE	REFERENCE
Stakeholder assessments *Tupicocha (PER) & Lurín (PER)*	• Participatory stakeholder assessment regarding technical concepts and policy mixes	• Multi-stakeholder dialogues and expert workshops	Chapter 3.4, 4.5
Topographical *Lurín (PER) & Klingenberg (DEU)*	• Digital elevation model (DEM)	• GeoSN (DEU) • NASA Aster (PER) • TanDEM-X mission (PER)	Chapter 3.1
Wastewater quality *Tupicocha (PER) & Lurín (PER)*	Tupicocha, wastewater treatment plants Cieneguilla and José Gálvez: • Chemical parameters such as COD, BOD, nitrogen and phosphorus compounds • Physical parameters such as temperature, pH, conductivity	• Own measurement • SEDAPAL (PER)	Chapter 4.4, 5.3
Water management *CHIRILU (PER)*	• Channel and piping networks • Dams • Irrigation units • Sanitation • Wastewater discharges • Water extraction • Water supply • Wells • Supplied volumes and quantities	• Own observations • ANA (PER) • LTV (DEU) • OA CHIRILU (PER) • SEDAPAL (PER) • INEI (PER)	Chapter 4.3, 4.4, 4.5, 5.2, 5.3, 5.4
Water quality (surface, raw, and drinking water) *Lurín (PER) & Klingenberg (DEU)*	• Chlorophyll a concentration • Heavy metals • Microbial community analysis • Phycocyanine • Physical-chemical parameters such as oxygen, temperature, turbidity, conductivity • Trace-organic compound • Microbiological parameters such as bacterial and viral indicators, total cell counts, bacterial specification	• Own measurements • OA CHIRILU (PER) • INGEMMET (PER) • SEDAPAL (PER) • DIRESA (PER)	Chapter 2.5, 4.3, 5.2

The TRUST GIS-Portal for Data Management and Visualization
Lucia Hahne

Some of the collected and recorded data from the TRUST project are stored and can be accessed via a GIS-Portal. Thus, we know what data are available and have information about the data's current status. In addition, we jointly developed metadata to facilitate searching the database. The search is supported by attributes such as keywords on the subject, scope, and time frame of the data. The metadata are designed with a focus on collaborative work. Fortunately, the GIS portal established good cooperation and sustainable data handling. As a unique feature of our GIS portal, the data are presented in attribute tables and map representation for visualization purposes (Figure 2.1). Thus, the data can be viewed and analyzed without additional GIS tools.



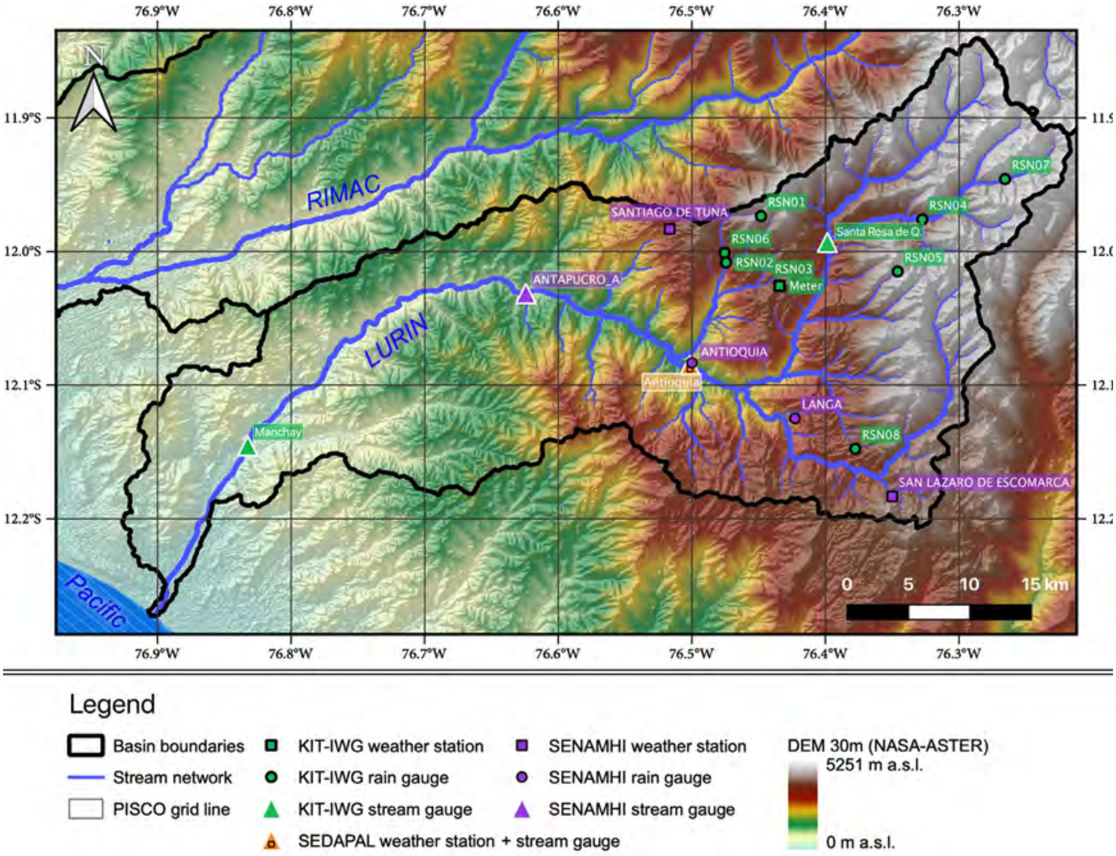
» *Figure 2.1:*
Exemplarily visualization of the GIS tool user interface.

2.2 Hydro-Meteorological Monitoring
Jan Bondy, Samuel Schroers, Jan Wienhöfer

To understand, quantify, and simulate the water balance and discharge dynamics within the Lurín catchment, we required data from hydro-meteorological monitoring stations and information about soil parameters. The most important parameters are precipitation and streamflow (discharge). Furthermore, data describing atmospheric conditions such as air temperature, solar radiation, relative air humidity, and wind speed are relevant. Soil moisture measuring is often not part of ground-based monitoring networks, even though it is a crucial parameter influencing fluxes at the ground-atmosphere interface.

Environmental monitoring designs should ideally reflect the nature of the investigated processes at the spatiotemporal resolution and extent of the corresponding measurement parameter. In an ideal hydro-meteorological monitoring setting, long monitoring time series are available at a high spatial resolution. However, for remote regions or regions with limited resources available for environmental monitoring, usually less data are available. Quantifying and modeling hydrological systems with a small amount of spatiotemporal data presents a key challenge in predictions in ungauged basins.

The data used to analyze the hydrology in the Lurín catchment and set up hydrological models are summarized in Table 2.1. The following section provides more details on the data retrieved from Peruvian environmental institutions and data collected by setting up new monitoring stations and field campaigns.



» *Figure 2.2: Map of hydro-meteorological monitoring stations in the Lurín catchment.*

2.2.1 Overview on Hydro-Meteorological Data in the CHIRILU Region

Only a few hydro-meteorological monitoring stations set up by the Peruvian weather service SENAMHI existed in the Lurín basin at the beginning of the TRUST project. These were mainly located in the central and southwestern parts of the catchment (Figure 2.2). We, therefore, installed additional stations in the northern and northwestern parts ("KIT-IWG stations" in Figure 2.2): Stream gauges (Section 2.2.3), rainfall gauges (Aerocone tipping buckets, Davis Instruments, USA; with Hobo Pendant loggers, Onset Computer Corp., USA), soil moisture measurements (SMT100 and TrueLog100, Truebner GmbH, Germany), and an automatic weather station (ATMOS 41, Meter Group, USA/Germany). In addition to data from monitoring stations in the Lurín catchment, we also retrieved data from the two neighboring catchments, Rímac, and Chillón, from Peruvian sources, namely SENAMHI and SEDAPAL (Table 2.1). Table 2.2 summarizes the monitoring stations in the CHIRILU region.

In general, the length of the available time series, the measuring interval, and the number and the kind of sensors vary from station to station. SENAMHI (see Table 2.2) has the most extended history of operating monitoring stations in the region. Their most recent weather stations acquire information about rainfall, temperature, relative humidity, solar radiation, air pressure, air temperature and automatically transmit data at an hourly time step. Other stations measure fewer parameters at lower frequencies, for example, daily rainfall amounts. Most of SEDAPAL's monitoring stations (see Table 2.2) are combined weather stations and stream gauges that were set up recently during the term of the TRUST project. Five weather stations measure all of the mentioned parameters, while others only measure precipitation and temperature. All stations transmit the data automatically at an hourly interval. The monitoring stations set up by KIT-IWG for the TRUST project collect stream water levels and weather data, including soil moisture values (Table 2.2). All monitoring stations measure data at a high temporal frequency with an interval between 5 and 10 minutes, but only the weather station transmits data automatically. The monitoring data collected by the stations during the TRUST project have been published as LAMA dataset, and are freely available (Schroers et al., 2021).

Daily precipitation amounts were also taken from the gridded precipitation data product PISCOp V2.1 (Peruvian Interpolation of the SENAMHI'S Climatological and hydrological data Observations - precipitation; Aybar et al., 2019). The dataset was derived by merging three different data sources: The national quality-controlled and infilled rain gauge dataset, satellite radar-derived climatologies for spatial patterns and seasonality (from TRMM data), as well as Climate Hazards Group Infrared Precipitation (CHIRPS) estimates. It covers Peru at a spatial resolution of 0.1° (about 10 km) from January 1981 to June 2018 (status as of June 2020).

» Table 2.2:
Monitoring stations operated in the CHIRILU region during the project term between 2017 and 2020. Stations of SEDAPAL and KIT-IWG were only set up during that time, while SENAMHI stations had been in operation before. The only SENAMHI stream gauge in the Lurín basin (at Antapucro) was destroyed in a flood event in March 2017, and was replaced with a contactless sensor in June 2018.*

OPERATOR	STATION TYPE	NUMBER OF STATIONS INSTALLED		
		LURÍN	RÍMAC	CHILLÓN
SENAMHI	Weather stations, rain gauges	4	22	12
	Stream gauges	1*	6	3
SEDAPAL	Weather stations, rain gauges	1	6	5
	Stream gauges	1	6	2
KIT-IWG	Weather stations, rain gauges	8		
	Stream gauges	2		
	Soil moisture monitoring	3		

2.2.2 Setting Up Monitoring Stations and Collecting Data in the Lurín Catchment

Most of the monitoring stations used within the TRUST project were installed at altitudes of 3000 m asl (stream gauge Santa Rosa) or higher. The only exception is the stream gauge Manchay at 229 m asl. In such an environment, the installation of the stations and the regular maintenance of the equipment was challenging. Most locations require a 4x4 off-road vehicle, but even with that, we could only access some sites during the low-flow period between May and November, when it is possible to cross the Lurín riverbed without bridges (Figure 2.3). The rainfall and meteorological stations were installed with the permission of the local farmers' communities near agricultural fields or irrigation reservoirs. In this way, the measurement equipment was placed on safe grounds and out of reach for non-local passers-by (Figure 2.4). Not only the successful installation of the monitoring network but also the maintenance and data collection were time-consuming and resource-intensive. Regular visits to the stations for checking the equipment, collecting data, and making calibrations and reference measurements are essential. Moreover, in the case of stream gauges, the development of consistent rating curves relating water level to stream discharge was of particular importance (Section 2.2.3).

We also conducted two measurement campaigns focussing on soil properties, for which we chose five sampling sites based on soil maps, topography, and land use information (see Table 2.1). The sites were each about 0.5 hectares in area. During the first campaign, we collected around 50 soil samples at each site, which were analysed for texture (the content of clay, silt, sand) and organic matter at the laboratory of Soils and Water at the Universidad Nacional Agraria La Molina, Lima. We also measured soil hydraulic conductivities with a hood infiltrometer (UGT GmbH, Germany; see Figure 2.4 left) and obtained additional soil samples, which were analysed at the soil laboratory of IWG. In a second campaign, we measured soil moisture using handheld sensors at these field sites, while IPF collected data with a hyperspectral camera mounted on an unmanned aerial vehicle (Section 2.3).

» ***Figure 2.3:*** *Crossing the Lurín River in the upper catchment is only possible with off-road vehicles during low-flow conditions. Picture: S. Schroers.*

» ***Figure 2.4:*** *Assessing soil hydraulic conductivity in the Lurín catchment using a hood infiltrometer (left). Rain gauge RSN05 in San Damián district at 4455 m asl (right). Pictures: J. Bondy.*

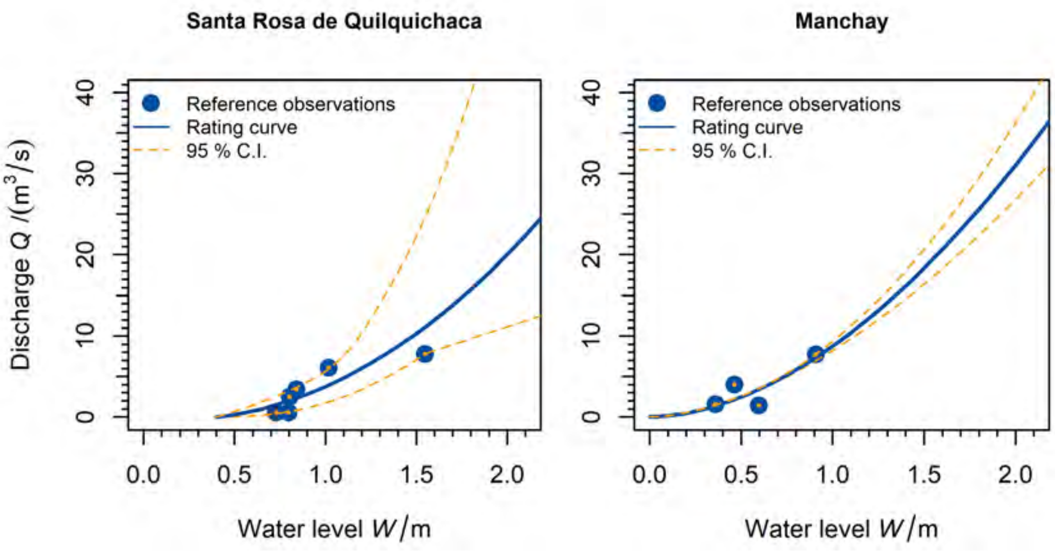
2.2.3 Stream Gauges and Rating Curves

The new stream gauges in the Lurín catchment (Manchay and Santa Rosa) were constructed at cross-sections defined by bridges. We attached flexible tubes to the rocks and foundations of the bridges (see Figure 2.5) and equipped these with water level loggers (Hobo U20L, Onset Computer Corp., USA). Limited funding did not allow for more sophisticated technical equipment and design; for example, building defined cross-sections, installing contactless sensors, or implementing automatic data transmission was not feasible.

For converting water levels to discharge, specific rating curves had to be defined for each station. We measured reference discharges using the tracer dilution method with salt or uranine (sodium fluorescein) on different dates. The observed discharges covered a range between 0.5 m^3/s and 7.8 m^3/s. Together with the corresponding water level observations, these were used to fit continuous rating curves for each station (Figure 2.6). The resulting rating curves‘ uncertainty is generally higher for high flows because obtaining independent discharge observations is less likely. The reference values - like every measurement - bear a relative measurement uncertainty. The river’s cross-section at Santa Rosa has an irregular shape due to the presence of large rocks and overhanging natural riverbanks, which further increases the uncertainty of the rating curve for both high and low flow conditions (Figure 2.6).

In conclusion, it is essential for successful stream gauging and hydro-meteorological monitoring that maintenance and reference measurements continue regularly. Obtaining new reference discharge observations can help improve rating curves or check for possible changes after high-flow periods. Analogously, rain gauges and weather stations need regular calibrations and maintenance.

*» **Figure 2.5:** Stream gauging station at Santa Rosa de Quilquichaca (3000 m asl): View on the installation at the right riverbank from the bridge above (the river flows to the left); the rectangle highlights the installation tube, which has a length of about 10 m (left). Cross-section and part of the river bed under the bridge, looking upstream (right). Pictures: S. Schroers.*



» Figure 2.6: Reference discharge observations and fitted continuous rating curves for stream gauging stations Santa Rosa (left) and Manchay (right). The 95 % confidence intervals were estimated from measurement uncertainty (right) and differential weighting of reference observations during non-linear fitting (left). Water levels are relative to the sensor position.

2.3 Remote Sensing Data Acquisition and Data-Driven Estimations in Peru and Germany

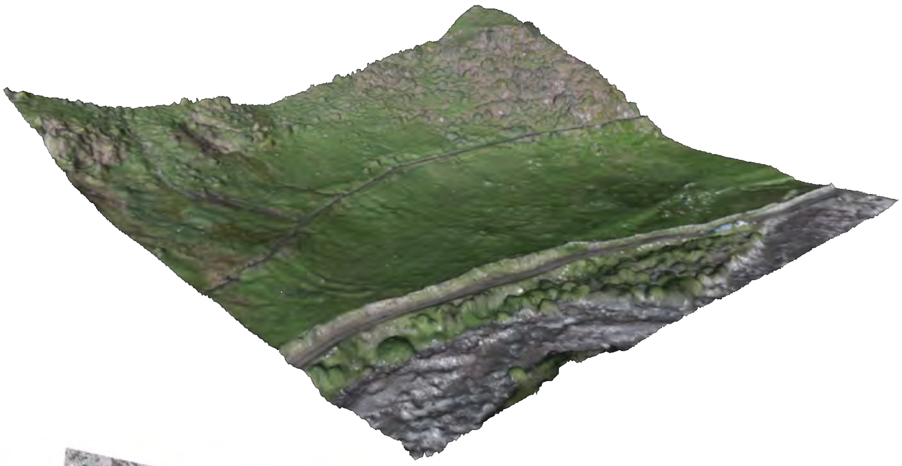
Felix M. Riese, Sina Keller, Stefan Hinz

Remote sensing of the earth includes the acquisition of imagery, for example, based on mobile platforms such as satellites and unmanned aerial vehicles (UAVs), the complex processing and analysis of the acquired remote sensing data, and the support of area-wide decisions with the processed data. Within the TRUST project‘s scope, the Institute of Photogrammetry and Remote Sensing (IPF) contributed various results based on different remote sensing data. These contributions are organized into six parts (see Table 2.1):

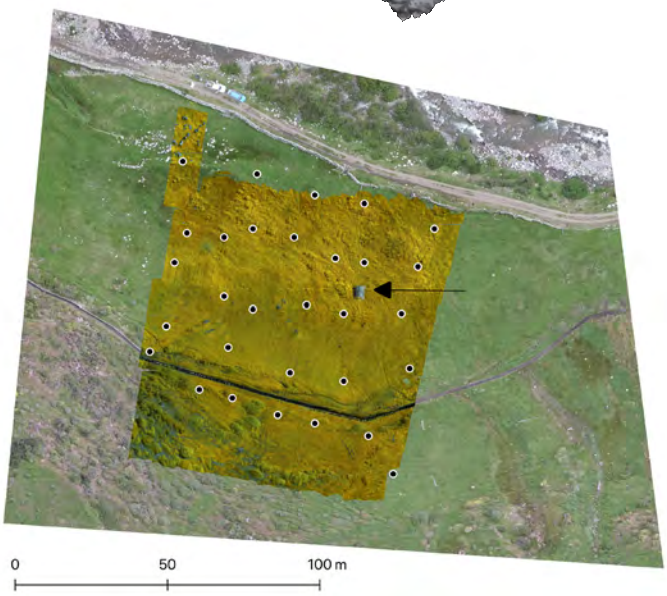
1. the delivery of a digital elevation model (DEM),
2. the development of machine learning (ML),
   methods for the soil moisture estimation with hyperspectral imagery,
3. the development of classification systems for the automatic detection of land-use changes with deep learning methods,
4. methods for the soil-texture classification with hyperspectral imagery,
5. the acquisition of large datasets from inland waters for the estimation of water quality parameters, and
6. the upscaling of the estimation to satellite scale.

In the following, these six contributions are briefly described and summarized.

The applied methodology is described in detail by Riese & Keller (2020) and Riese (2020) . Our methodological approaches mainly rely on data-driven ML as a part of artificial intelligence. In general, the estimation of a variable with ML approaches follows four levels: the sensor level, the data level, the feature level, and the model level. In the case of our estimations in TRUST, the variables are land use classes, soil moisture values, soil texture classes, and water quality parameter values. The sensor level includes measurement campaigns with several sensor systems to record the remote sensing data and corresponding reference data. For example, we calculated a digital elevation model of an area at the Lurín catchment based on RGB images captured by a camera mounted on a UAV (see Figure 2.7).



» *Figure 2.7:*
Digital elevation model (DEM) of an area at the Lurín catchment (see Riese et al., 2020b) generated from an UAV, which is equipped with an RGB camera.

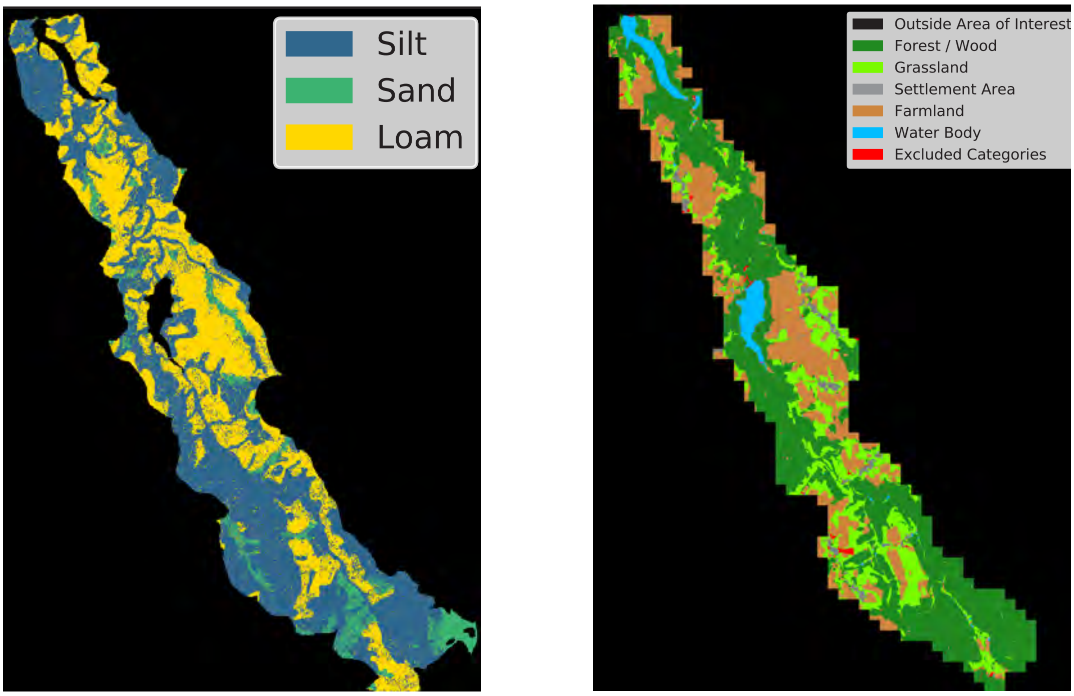


» *Figure 2.8:*
Aerial image of a measurement area in Peru with a red-green-blue camera and a hyperspectral camera, both mounted on UAVs. A white reference marked by an arrow is placed inside the measurement area for the camera calibrations. Additionally, soil-moisture reference data (black circles) was acquired. (Taken from Riese, 2020)

For the estimation of soil moisture, soil moisture measurements were conducted in several regions of the Lurín catchment (Section 2.2.2). The data level includes the pre-processing of the acquired data and the dataset splitting, which is, for example, necessary to evaluate the model performance and the generalization capabilities of an applied model.

Within the TRUST project, we generated and published three datasets combining soil moisture probe measurements and hyperspectral data: the KarLy dataset, the HydReSGeo dataset, and the ALPACA dataset (Riese & Keller, 2018; Keller et al., 2020; Riese et al., 2020b). Besides, our SpecWa dataset containing chlorophyll a values and spectral data, is also freely available (Maier & Keller, 2020). In Figure 2.8, a measurement area applied for the ALPACA dataset is shown. For the area-wide estimation of selected variables with the developed methodological approaches, freely available data of the ESA Sentinel-2 mission were used for study areas located in Peru and Germany. Exemplary estimations of soil texture and land use based on Sentinel-2 data are shown in Figure 2.9. Further, the openly available European soil database LUCAS was included in the estimation of soil texture

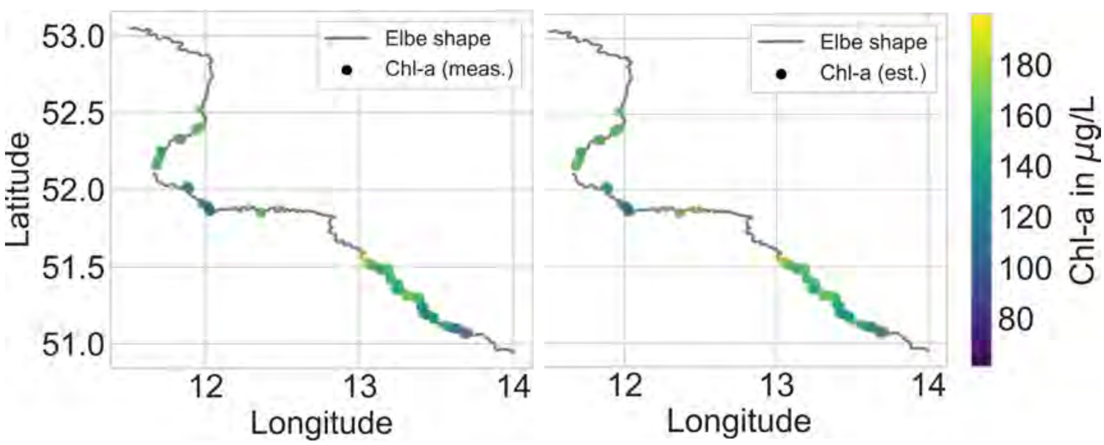
At the feature level, relevant features were extracted from the hyperspectral data with unsupervised clustering approaches or approaches to reduce the dimensionality of the high-dimensional data. Based on these approaches, we were able to deepen the understanding of the hyperspectral input data and the estimation task itself. At the model level, either supervised or semi-supervised



» *a* » *b*

» ***Figure 2.9:*** *Machine learning classification of (a) soil text ure and (b) land use and cover based on ESA Sentinel-2 data, both for the catchment of the Klingenberg reservoir in Saxony, Germany. (Left: Taken from Rothfuß, 2019)*

ML models were selected depending on the estimation task, which had to be solved. Mostly, the choice of which model was used is defined by the availability of reference data. To sum up the contributions at the feature and model level, we developed an estimation framework including (semi-)supervised self-organizing maps for distinct estimation tasks, especially when only limited labeled data is available, as described in more detail by Riese et al. (2020a). We implemented three innovative convolutional neural network architectures as methodological output for the classification of soil texture with hyperspectral spectrometer data, introduced by Riese & Keller (2019). These models function purely data-driven and include state-of-the-art ML research. Further, we presented an automatic detection of land-use changes with long short-term memory (LSTM) networks. These LSTM networks are characterized by learning from several satellite image sequences rather than from single images. Therefore, the developed LSTM networks can differentiate classes and processes that change during time, such as during different seasons of a year. Besides, the estimation of soil moisture and water quality parameters such as chlorophyll a concentration is realized with a developed and implemented ML framework. This framework is described in detail by Keller et al. (2018a, b), and its exemplary results for a measurement campaign along the river Elbe in Germany are illustrated in Figure 2.10.



» ***Figure 2.10:*** *Example for the visualization of the true values (left) and estimated values (right) of chlorophyll a along the river Elbe. (Taken from Keller et al., 2018a)*

Exemplary Acquisition of Reference Data for Remote Sensing Applications
Friederike Brauer

To develop a classification system for the automatic detection of land-use changes (see objective (3) of Section 2.3), reference data on land use and land cover is necessary for the deep learning methods. For the catchment of the Klingenberg reservoir (Germany), these reference data were obtained from the German Digital Landscape Model of the Official Topographic-Cartographic Information System (ATKIS Basis-DLM), which contains digital, object-structured vector data and serves as a basis for generating topographical maps. Information on land use and land cover were gathered from the various shapefiles and summarized in a standardized way. Thus, a detailed shapefile presenting the land use and land cover in the area was generated and used as reference data to train the deep learning methods. The results of the land use and land cover classification are shown in Figure 2.9b.

Besides information on land use and land cover, information on the permeability of the topsoil was collected. Several possibilities exist to determine the permeability experimentally at a test site. At the Klingenberg test site in Germany, a double ring infiltrometer (Figure 2.11) was used to estimate the permeability at different locations. To obtain information for larger areas, the approximate permeability was derived from data on the soil texture from the soil map 1:50 000. The soil map is generated from point information gathered in the field and collected by the Saxonian State Office for Environment, Agriculture, and Geology. In the first step, the information from the map was used as a reference. In a second step, the original point information was used to avoid difficulties arising from generalizations in the map. Results of the ML classification of the soil texture are presented in Figure 2.9a.

» *Figure 2.11:*
Permeability measurement with a double ring infiltrometer at the test site Klingenberg, Germany. Picture: F. Rees.

2.4 Stakeholder Analysis and Participation for Conflict Transformation
Christian D. León & Hannah Kosow

A decisive factor in water management at the river basin level is an in-depth analysis of the relevant stakeholders, a so-called stakeholder mapping. We define stakeholder as a person, group, or organization that has an interest or concern in water management and who can affect (or is affected by) water management policies and actions. Relevant stakeholders include all water users located along a river or river basin as well as public or private actors, who define policies, provide financial resources, and make decisions that positively or negatively affect water users.

Before conducting a stakeholder analysis, the first step is to analyze the political, cultural, and geographical conditions. This first analysis helps to better understand which stakeholders exert, either directly or indirectly, influence in the study area. For this purpose, the different political levels (national – regional – local) and their relationships of influence were analyzed. For example, actors outside of a watershed may need to be taken into account because they indirectly influence actors in the watershed through their activities (e.g., markets, production).

As sources of information, we have referred to publications on the region and the topic, such as academic and popular science articles, newspaper articles, book contributions and policy reports, legal texts, and master/bachelor theses. Extensive internet research has enabled us to update and supplement information on the players involved (see Table 2.1 "actors and government structures"). To learn more about actors and their goals, interviews with locally active organizations and key persons were vital information sources. This holds especially true for actors in the upper catchment area of the Lurín, as the information situation for this area is relatively low.

» *Figure 2.12: Participants of the stakeholder workshop in discussion. Picture: C. D. León.*

The following classification has proven to be useful for categorizing the stakeholders: 1) state/governmental actors, 2) non-governmental organizations (NGOs), 3) civil society actors, 4) research organizations and universities, 5) private sector actors and 6) international actors. Hybrid forms are also possible. Within their respective categories, the actors were listed according to the degree of their involvement in the research topic. The key actors are those who are directly affected or involved. This classification is important since the aim of the stakeholder analyses is to assess which actors need to be involved to what degree and at what time in a participatory process.

Even though participatory processes require considerable time and resources, they offer stakeholders an important opportunity to become familiar with management options and participate in decision-making processes Increased participation can ultimately lead to greater ownership of the outcome, increased credibility and acceptance, or recognition of the intended and necessary measures, policies and objectives (Behnke & Schwaiger, 2019).

According to the International Association for Public Participation (2018), participation can occur in five different intensity levels. First, it can be limited to information communication and the sharing of knowledge (Inform). On a second level, participation takes place by consulting for feedback (Consult). On a third level, there is regular and intensive involvement in the process (Involve). On the fourth level, participation takes place in the form of partnership in developing appropriate solutions (Collaborate). On the fifth and last level, participation is carried out to enable the stakeholders to develop solutions and implement them independently (Empower).

One focus of the TRUST project was the involvement of water users and stakeholders, as well as experts and decision-makers in the research process. Involvement was organized in different formats: Focus groups with specific user groups (e.g., women), multi-stakeholder dialogues, and assessment workshops to include relevant actors in developing innovative water management concepts. More specifically, these participatory assessment workshops with stakeholders contributed substantially to gaining a more socio-technical perspective (see Chapter 4).

Managing water resources in water-scarce regions also means to manage potential conflicts between goals and interests of various water users in a catchment. Different actions (policies) can be chosen to reach different water-related goals. A range of policy tools (e.g., measures and instruments) needs to be combined to reach multiple goals. Such policy tool combinations - also called policy mixes - cannot be assembled freely or arbitrarily, as policy tools can contradict and support each other. We applied qualitative systems analysis to understand potential water use conflicts and design integrated, consistent, and sustainable policy mixes to prevent these. Cross-impact balance analysis (CIB, Weimer-Jehle 2006) was used to assess interactions between alternative policies to reach (potentially) conflicting objectives of different central water users (agriculture, households, tourism, industry, and ecosystems) in different parts of the Lurín catchment. The process comprised desk research, expert consultation, and stakeholder involvement. Table 2.3 summarizes 14 central objectives with 2 to 5 alternative policies each to achieve these objectives (in total, 47 policy options). We have identified the objectives as well as the policies through literature review and stakeholder consultation. We interviewed local actors (n = 19) and technical experts (n = 10) to learn about fostering and hindering interrelations between policy options and different objectives. All assessments taken together formed a conceptual yet formalized policy-interaction model (see Figure 3.12 in Chapter 3.4). The CIB balance algorithm allowed to identify alternative but consistent and synergetic policy mixes for the entire Lurín catchment and to assess their contribution to attain different targets of SDG 6 (cf. Kosow et al. 2019 and 2020 for more information on the methodology). The identified policy mixes served also as knowledge input for local participation and planning processes (Chapter 3.4).

» ***Table 2.3:*** *Central water use related objectives and policies in the Lurín catchment*

NO.	WATER USER	MAIN OBJECTIVE	ALTERNATIVE POLICIES			
			UPPER CATCHMENT AREA			
1	Households and tourism	Ensure sufficient drinking water (quantity)	**1a** Own resources (including reservoirs)	**1b** Supply from remote resources	**1c** Water metering and tariffs	**1d** Drinking water saving technology
2	Households and tourism	Ensure the quality of drinking water for health protection (quality)	**2a** Treatment in households	**2b** Central drinking water treatment	**2c** Prevention of contamination (local)	
3	Households and commerce	Safe treatment and disposal of domestic and commercial wastewater	**3a** Infiltration or direct disposal (status quo)	**3b** Central treatment	**3c** Treatment with material flow separation	

NO.	WATER USER	MAIN OBJECTIVE	ALTERNATIVE POLICIES				
4	Agriculture	Ensure sufficient water availability to expand agricultural areas	**4a** Reservoirs	**4b** Traditional means (andenes, cochas etc.)	**4c** Increasing water efficiency	**4d** Reuse of treated wastewater	
5	Ecosystems	Long-term conservation of water-related ecosystems in the upper catchment area.	**5a** Green infrastructure	**5b** Regulation of water resources (Protected areas and near to nature outflow)			
LOWER CATCHMENT AREA							
6	Households and tourism	Ensure the access and the distribution of the drinking water for the growing population	**6a** Water trucks	**6b** Public drinking water and wastewater network	**6c** Local drinking water and wastewater network		
7	Households and tourism	Ensure sufficient drinking water to supply the growing population (quantity)	**7a** Groundwater	**7b** River water	**7c** River water transfer (from other catchment areas)	**7d** Unconventional alternatives	**7e** Artificial groundwater recharge
8	Households and tourism	Ensure the quality of the drinking water for health protection (quality).	**8a** Treatment in households	**8b** Central drinking water treatment (level of wells)	**8c** Prevention of contamination (local)		
9	Households and tourism	Water saving and efficient use of the drinking water	**9a** Water metering and tariffs	**9b** Drinking water saving technology in households	**9c** Water culture and behavioral change		
10	Households and tourism	Safe treatment and disposal of municipal wastewater	**10a** Central primary treatment (» Pacific Ocean)	**10b** Central secondary treatment (»River)	**10c** Central tertiary treatment	**10d** Decentralized treatment with multiple use	
11	Agriculture and green areas	Ensure sufficient water for irrigation in agriculture and of green areas.	**11a** Groundwater	**11b** River water	**11c** Increasing water efficiency	**11d** Reuse of treated wastewater	
12	Industry	Ensure sufficient process water for (agro-) industrial activities (quantity)	**12a** Private groundwater wells	**12b** Private desalinization of sea water	**12c** Treated wastewater (multiple use)	**12d** Public drinking water network	
13	Industry	Safe treatment and disposal of industrial wastewater	**13a** Disposal through municipal treatment plants without pretreatment	**13b** Internal pretreatment and indirect discharge	**13c** Decentralized treatment and direct discharge		
14	Ecosystems	Long-term conservation of water-related ecosystems	**14a** Conservation of green areas	**14b** Regulation of water resources (protected areas and regulation of extractions)			

2.5 Monitoring of Water and Wastewater Quality

Michael Hügler & Stefan Stauder

The usage of different water sources (rivers, lakes, reservoirs, springs and groundwater) for drinking water production places a wide range of demands on water treatment. Due to the high vulnerability of surface water against environmental influences, there are potential health risks, both for the use as drinking water, as well as for other types of usages such as irrigation. Especially river water is subject to strongly fluctuating water qualities and can exhibit very high fecal loads. The same holds true for lakes and dams, although the hygienic load is generally lower than in river waters. Besides hygienic risks, there are also risks through chemical substances such as heavy metals (e.g., from mining and industry), organic trace substances (e.g., biocides from agriculture), or toxins (e.g., from cyanobacteria blooms). Furthermore, wastewater poses a significant health risk if it is not treated properly when released to the river, or used for irrigation.

The water use patterns in the Lurín catchment differ significantly between the upper and lower catchment areas. In the upper catchment, mainly surface water, i.e., rainwater stored in artificial reservoirs, and spring water is used as a drinking water resource and for irrigation. In contrast, in the lower catchment, groundwater is the primary water resource for drinking water, irrigation, and industry (see Chapters 4 & 5 for details). To evaluate the situation in the Lurín catchment with respect to the achievement of SDG 6 (clean water and sanitation), water quality needs to be monitored and evaluated. As minimal data was available, monitoring concepts were developed and applied in the Lurín valley (see Table 2.1 "water quality" and "wastewater quality"). Water quality analyses included reservoirs, springs, drinking water distribution networks, and wastewater discharges in the upper catchment area. Within the lower catchment area, groundwater wells (run by SEDAPAL and farmers), wastewater discharges of two wastewater treatment plants (Cieneguilla and José Gálvez), and the Lurín river itself were monitored. The water quality was analyzed comprehensively in the TZW laboratory, complemented by on-site measurements of sensitive parameters like O_2, pH, and turbidity. The laboratory analyses included main and trace elements, as well as persistent organic pollutants (e.g., pharmaceuticals, industrial chemicals, and pesticides). In order to assess the microbial water quality, bacterial and viral indicators, like E. coli, coliform bacteria, enterococci, Clostridia, and somatic coliphages, as well as heterotrophic plate counts (HPC) and total cell counts (TCC), were analyzed. Selected samples were subjected to more detailed analyses with the bacterial specification or the measurement of antibiotic-resistant bacteria and index pathogens.

Furthermore, as part of the wastewater sampling campaign, composite samples were taken at two-hour intervals (8 a.m. – 8 p.m.) from the influent of the wastewater treatment plants Cieneguilla and Jose Galvez. Subsequently, they analyzed for their constituents (chemical oxygen demand (COD), biological oxygen demand (BOD_5), total organic carbon (TOC), total suspended solids (TSS), total kjaeldahl nitrogen (TKN), ammonium (NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N), phosphate (PO_4-P) and total phosphorus (P_{tot})). In Tupicocha, wastewater from a discharge into a gully was sampled (6 a.m. – 6 p.m).

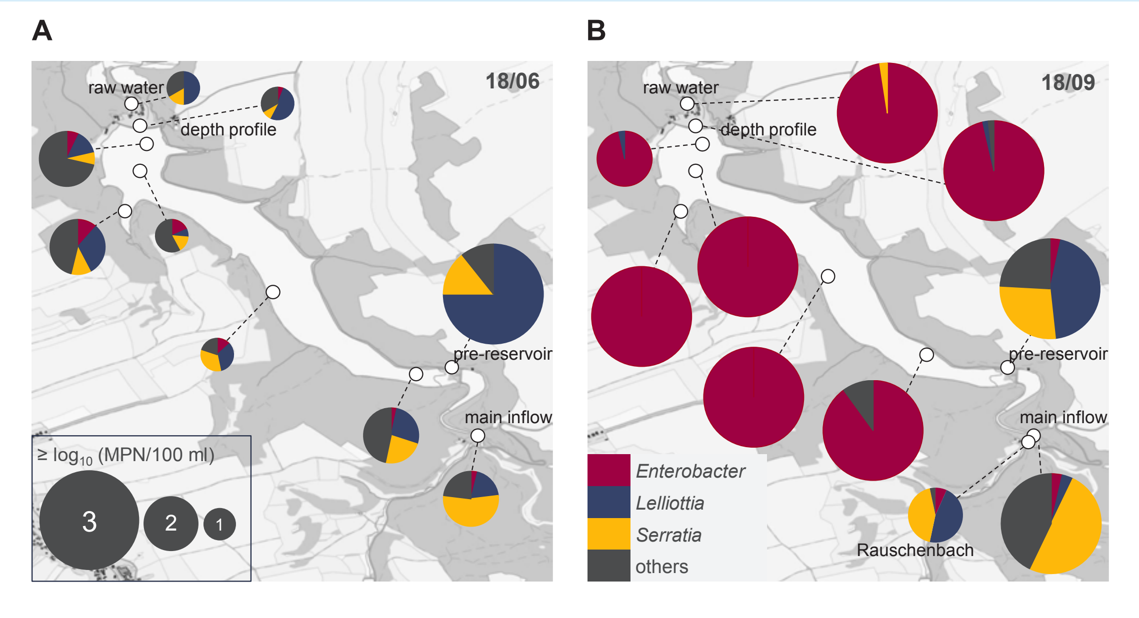
Monitoring of Microbiological and Physical-Chemical Water Quality at Klingenberg Reservoir

Michael Hügler

i

Especially in regions with water scarcity, reservoirs and dams are a significant source for drinking water production. Major problems concerning water quality arise from blooms of potentially toxic cyanobacteria, and possible mass proliferations of hygienically relevant bacteria like coliform bacteria. To investigate these water quality issues, we planned and performed a comprehensive monitoring program at the Klingenberg test site, a reservoir used for drinking water production in Saxony, Germany (see Table 2.1 “water quality”). In addition to the standard water quality analyses performed by the Landestalsperrenverwaltung (LTV), we installed a multi-parameter sensor provided by the project partner OTT Hydromet for the online analyses of temperature, turbidity, oxygen content, salinity, chlorophyll a and phycocyanin (cyanobacterial pigment).

Water samples from the reservoirs were taken on a two to four weeks basis and analyzed for microbiological parameters. Besides, two sampling campaigns were carried out during which the entire reservoir, the depth profile, and all inflows were sampled and tested for additional microbiological parameters, including fecal marker genes (see Stange et al. 2019 for analytical details) and analyses of the microbial community. Coliform bacteria were further specified to see which species were present and which species can proliferate in the reservoir. Our studies showed that the mass proliferation of coliform bacteria is an autochthonic process in the water column and occurs during the summer months. A single strain of the genus *Enterobacter* was responsible for this “coliform bloom” (Figure 2.13; see Reitter et al., 2021, for further details). The multi-parameter sensor proved to be useful for the detection of algal blooms. High chlorophyll concentrations were present in spring and could be assigned to diatoms. In contrast, we could not detect high chlorophyll concentrations during the two sampling campaigns.



» *Figure 2.13:*
Quantification and identification of coliform bacteria at the Klingenberg reservoir during the sampling campaigns in June (left) and September 2018 (right). (Taken from Reitter et al., 2021).

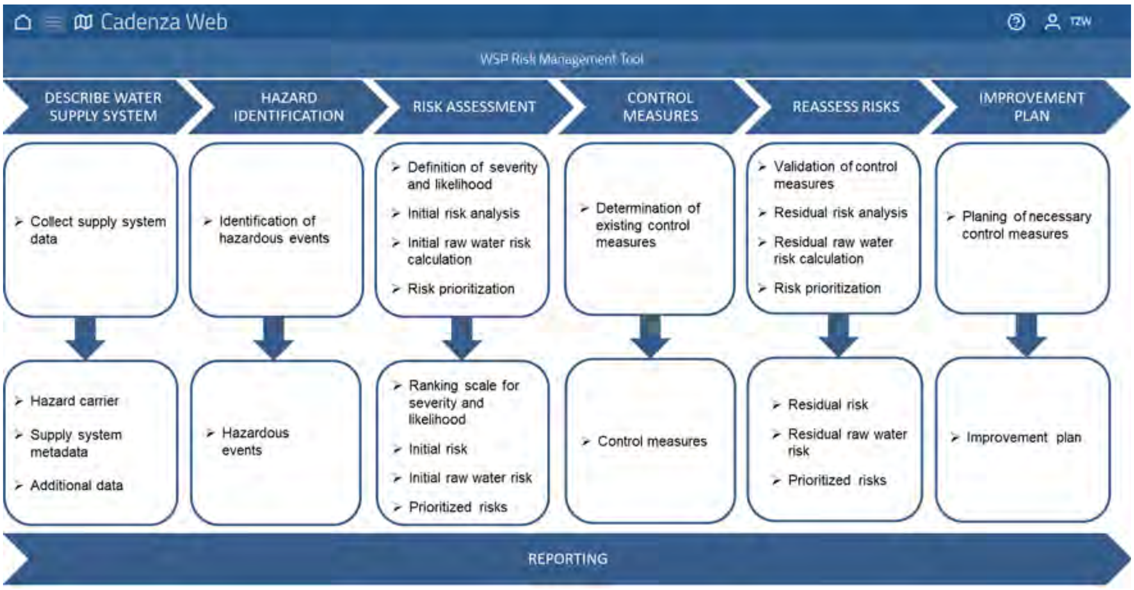
2.6 Water Safety Plan-Tool

Friederike Brauer, Thilo Fischer, Lucia Hahne, Sebastian Sturm

Assuring the long-term quality of drinking water is the principal objective of preventive resource protection. Establishing a risk management system, for example a Water Safety Plan (WSP), is an important instrument in this context. In the update to the WHO guidelines for drinking water quality, the WHO has recommended implementing a WSP since 2003. The WSP concept is a risk-based approach to drinking-water quality management and is the international point of reference for safe management of drinking-water supply from catchment to tap. It is regarded by the WHO as an essential, globally applicable instrument for safely achieving the strategic development goal for clean drinking water at local level (WHO, 2003).

Implementing a risk management system involves a great deal of effort. Especially a spatially resolved assessment of the catchment area is very time-consuming. As part of the TRUST project, we developed a prototype of a decision support system to facilitate the implementation of a risk management system. Its structure is based on the WSP-concept. Further information on the design of the application can be found in Gottwalt et al. (2018 a + b) and Brauer et al. (2019).

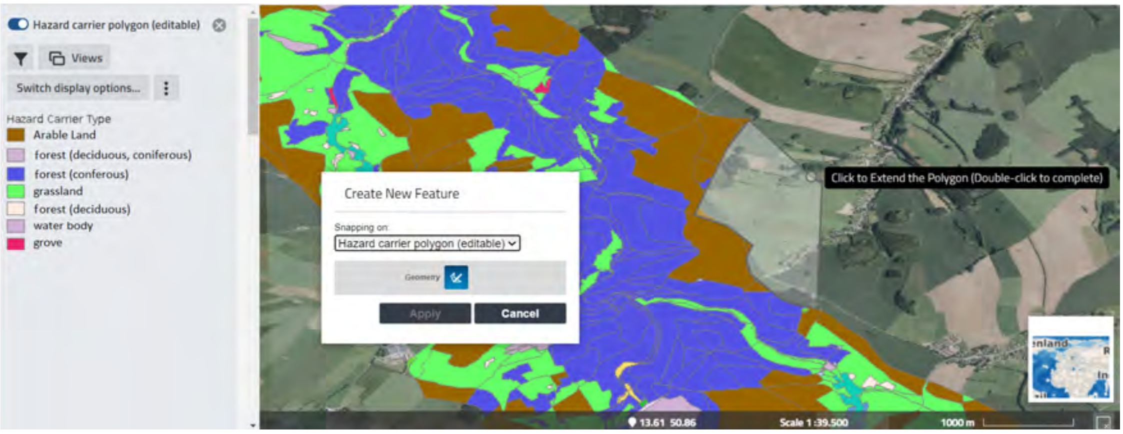
The decision support system was implemented as a database-based specialist application. It focuses on risk analysis in the catchment area but also facilitates risk analysis for further process steps in water supply chains like water catchment, storage and distribution. It supports a targeted management of water resources and provides a basis for the development of monitoring systems and further measures to ensure water quality.



» *Figure 2.14: Homescreen of the Water Safety Plan-Tool.*

The interactive application enables recording and assessing risks in the water supply system and documenting measures to control risks (Figure 2.14).

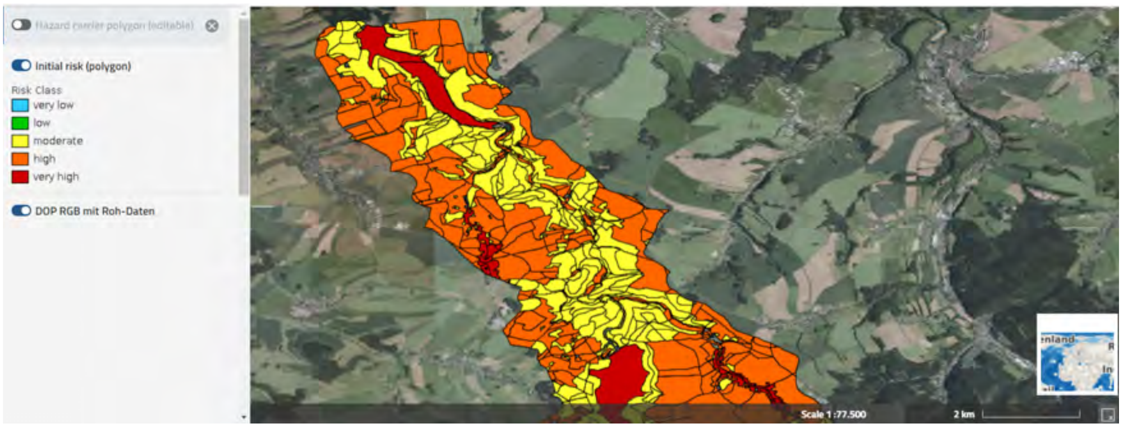
For hazard analysis, existing data on land use or activities in the area may be used. The user can also create new features within the tool (Figure 2.15). In the next step, hazardous events can be assigned to those hazard carriers. For example, organic fertilization can be assigned to the corresponding part of the arable land. The initial risk for every hazardous event is calculated within the tool based on severity of consequences and likelihood of occurrence, which the user can rate on a 5-level-scale from very low to very high. The reasons leading to the rating are to be documented within the tool. The initial risk then is the same for



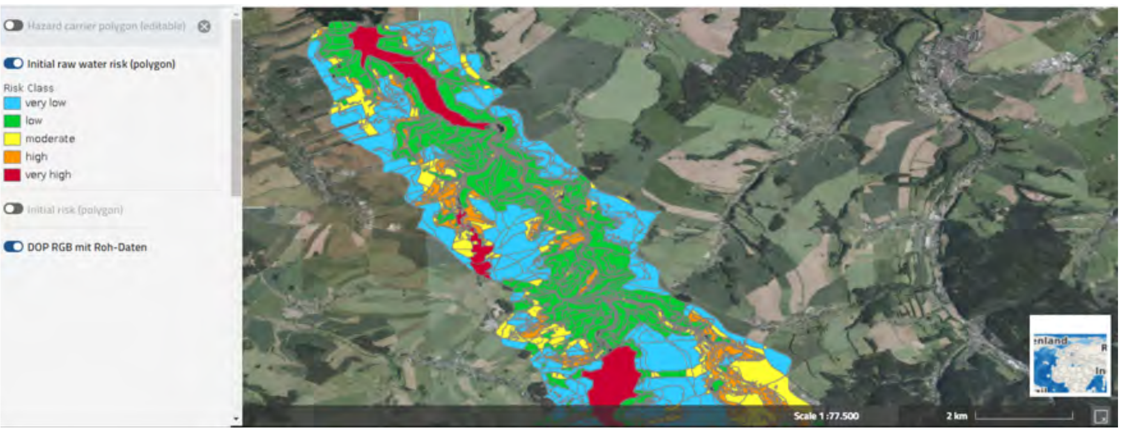
» *Figure 2.15: Recording of hazard carriers in the map (test area Klingenberg, Germany).*

every object of one kind, regardless of the location within the catchment area. For example, every organically fertilized area of arable land is rated equally at this point (Figure 2.16). Both the initial risk arising from the uses and actions and the vulnerability of the areas are taken into account to assess the arising risk for the raw water. Thus, in addition to information on land use, data on area characteristics such as slope inclination and soil type as well as distance to the extraction point can be included into the evaluation. This results in a spatially differentiated risk assessment and shows clearly, which areas are most likely to lead to significant water quality issues (Figure 2.17). In the following step, risk management measures can be assigned to those hazard carriers, which lead to significant risks. The results show where action is required.

The WSP-Tool supports uniform documentation and minimizes the effort required to maintain the WSP by automated calculations and by keeping all data in a single database and thus avoiding redundant entries. Adding the spatial component, which is indispensable for a targeted catchment area risk management, represents a significant benefit compared to previously available tools to create and maintain a WSP.



» *Figure 2.16: Initial risk in the catchment area shown in a map (test area Klingenberg, Germany).*



» *Figure 2.17: Initial raw water risk in the catchment area (test area Klingenberg, Germany).*

2.7 Sustainable Development Goal 6 - Targets and Indicators

Hanna Kramer

2.7.1 Sustainable Development Goal 6 - Targets

Sustainable Development Goal 6 „Ensure availability and sustainable management of water and sanitation for all“ includes eight sub-goals, called targets. Each target has a different focus to address the current problems related to water, sanitation and the affected environment (Figure 2.18). The first two targets address the human right to safe drinking water (Target 6.1) and adequate sanitation (Target 6.2). Target 6.3 aims at improving water quality by reducing pollution and halving the proportion of untreated wastewater. Further targets tackle water use efficiency (Target 6.4), integrated water resources management Target (6.5), and the protection and restoration of water-related ecosystems (Target 6.6). Targets 6.A and 6.B address international cooperation and support through capacity building, and supporting the participation of local communities, respectively.

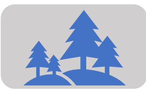
6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all

6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate



6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

6.A: By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

6.B: Support and strengthen the participation of local communities in improving water and sanitation management

» *Figure 2.18: SDG Targets*

2.7.2 Sustainable Development Goal 6 - Indicators

SDG 6 and its associated targets are very ambitious as they attempt to broadly cover existing problems. However, setting the targets is merely the beginning. In the best case this is followed by possible measures to achieve these targets. Finally, measures have to be evaluated to determine whether the achievement of the targets has moved closer.

For this purpose, one or more indicators for each target record the status quo and measure the development achieved over time. In total, eleven indicators for progress on SDG 6 targets have been defined by the Inter-Agency and Expert Group on Sustainable Development Goal Indicators, considering issues of relevance, methodological soundness and measurability (ECOSOC, 2016).

For monitoring of the eleven global SDG 6 indicators, three monitoring programs are in place, consisting in total of eight organizations of the United Nations. The first program JMP (Joint Monitoring Program) is responsible for monitoring progress on drinking water, sanitation and hygiene (SDG targets 6.1 and 6.2) led by WHO and UNICEF. The Second GEMI (Global Environmental Management Initiative) program tracks progress on wastewater, water quality, water resources management, and water-related ecosystems (SDG targets 6.3-6.6) and is composed of FAO, UN-ECE, UNEP, UNESCO, UN-HABITAT, UNICEF, WHO and the World Meteorological Organization. The third monitoring program GLAAS (Global Analysis and Assessment of Sanitation and Drinking-Water) is responsible for SDG targets 6.A and 6.B. It monitors finances, capacities and the enabling environment and is composed of WHO, UN environment and OECD (UN Water 2018).

The monitoring organizations publish regular reports to provide global analysis for informed decision-making. These reports include „Step by Step methodologies“ to provide consistent guidance on how to monitor, calculate, and implement each of the global SDG 6 indicators. The Step by Step methodologies can be accessed under https://unwater.org/publications/.

2.7.3 TRUST Concept Evaluation

The TRUST project used SDG 6 indicators to assess the status quo situation in the Lurín catchment and to evaluate the anticipated effects of the integrated concepts on achieving SDG 6. For this purpose, the Step by Step methodologies were used. The TRUST concepts focus mainly on the provision of safe drinking water and adequate treatment of wastewater. Therefore, we primarily applied the indicators 6.1.1 and 6.3.1, which are the indicators for targets 6.1 and 6.3, respectively. The concepts have further positive indirect impacts on the achievement of other SDG 6 targets due to the strong linkages between the targets, nevertheless.

The achievement of indicator 6.1.1 “proportion of population using safely managed drinking water services” is monitored using a service ladder, which was established by the JMP and classifies different access situations into five levels, ranging from safely managed drinking water to surface water use (Figure 2.19a).

In the same way, the progress towards target 6.2 is monitored using the indicator 6.2.1 “proportion of population using safely managed sanitation services, including a handwashing facility with soap and water”. The sanitation service ladder classifies the different sanitation conditions from safely managed sanitation to open defecation (Figure 2.19b). Safely managed is defined as "use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site" .

The evaluation of the status quo for indicator 6.3.1 „proportion of wastewater safely treated" is based on the Step by Step methodology. The input data required for calculating the percentage of treated wastewater include information on sanitary infrastructure and its condition, possible collection forms and transport (an example calculation of indicator 6.3.1 can be found in WHO & UN-HABITAT, 2018). Tthe local regulation standards for wastewater treatment should also be matched to the definitions of the indicator. Particular attention should be paid to the level of treatment in relation to the end use (UN Water, 2016). In order to obtain the necessary data for the evaluation of the status quo, mainly census data were used, and complemented with information from administrative sources and regulators, as well as own measurements and qualitative surveys.

a) Drinking Water Service Ladder	b) Sanitation Service Ladder
Safely managed Drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination	**Safely managed** Use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site
Basic Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing	**Basic** Use of improved facilities which are not shared with other households
Limited Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing	**Limited** Use of improved facilities shared between two or more households
Unimproved Drinking water from an unprotected dug well or unprotected spring	**Unimproved** Use of pit latrines without a slab or platform, hanging latrines or bucket latrines
Surface water Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal	**Open defecation** Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches and other open spaces or with solid waste
Note: Improved drinking water sources are those that have the potential to deliver safe water by nature of their design and construction, and include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water	Note: Improved sanitation facilities are those designed to hygienically separate excreta from human contact, and include: flush/pour flush to piped sewer system, septic tanks or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs

» ***Figure 2.19:***
Drinking Water Service Ladder (a) and Sanitation Service Ladder (b) (WHO & UNICEF, 2017).

Data Gaps - What can be done

A transect walk has proven to be a helpful method for obtaining additional information. In March 2018 an inspection of relevant water and sanitation infrastructure to evaluate SDG indicator 6.1.1 and 6.2.1 was undertaken in San Andrés de Tupicocha by TRUST experts together with students of the Cesar Vallejo School. Through the collection of further qualitative data, census data can be supplemented and important additional information can be gathered to verify existing data (Kramer et al., 2020).

» ***Figure 2.20:***
Site inspection with students of the Cesar Vallejo School in San Andrés de Tupicocha.
Pictures: H. Kramer (above), C. D. León.

3. The Lurín Catchment: Geography, Hydrology, Governance, and Water Use Conflicts

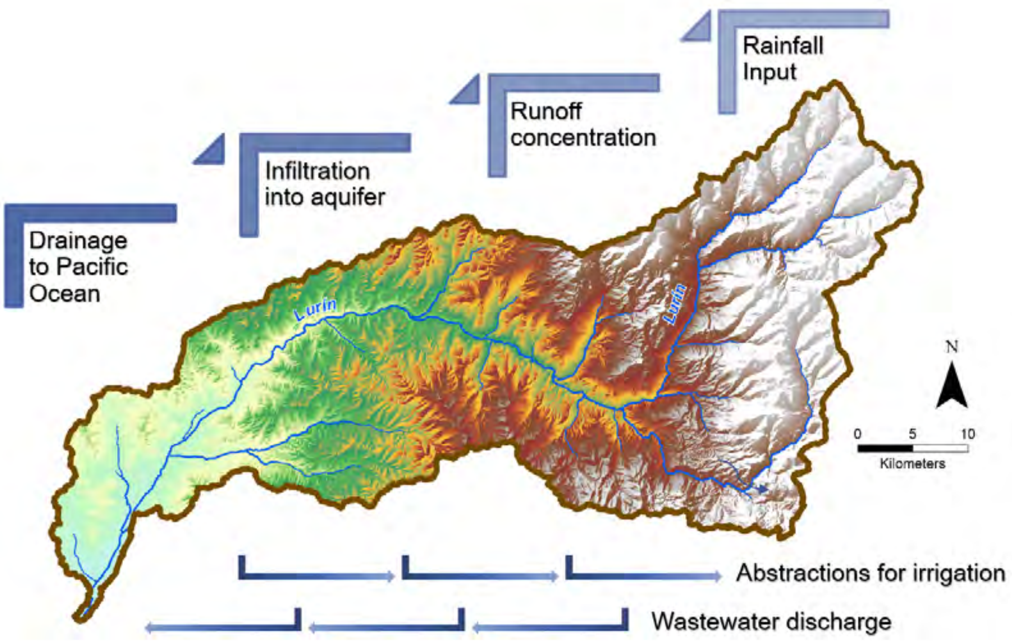
Organizing authors: Jan Wienhöfer & Hannah Kosow

Picture: F. M. Riese

3.1 Overview on Geography, Demography and Water Management of the Entire Catchment

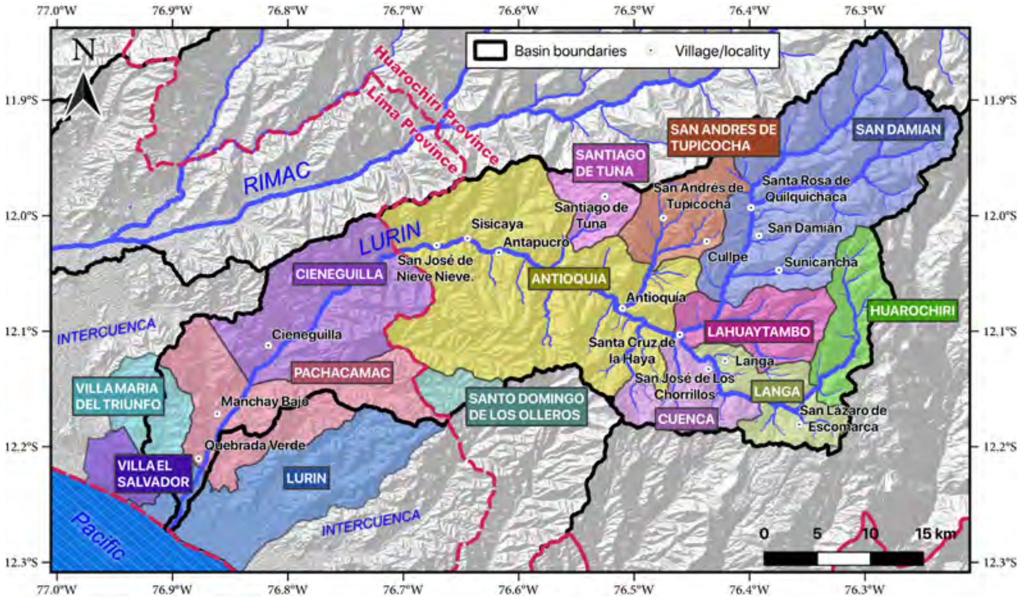
Jan Wienhöfer, Hannah Kosow, Stephan Wasielewski, Jan Bondy, Christian D. León, Manuel Krauss

The Lurín catchment is located southeast of Lima (between 11°45’ and 12°15’ S, 76° and 77° W) and has an area of 1 670 km². The Lurín is about 111 km long, has its source in the Western Andes at about 5 250 m asl, and discharges into the Pacific Ocean. The climate is influenced by the topography and the Pacific Ocean. Rainfall occurs almost exclusively during the austral summer (from November until April). Average rainfall sums are reported to be around 600 mm per year in the higher parts, and virtually zero at the coast. Discharge of the Lurín, which is reported to be around 5 m³/s on average, shows a similarly pronounced seasonality as the rainfall (Observatorio del Agua Chillón Rímac Lurín, 2019). After entering the lower parts of the catchment in the district of Cieneguilla, the Lurín loses a significant part of its water, and even falls dry completely towards the end of the dry season. The river water infiltrates into the valley bottom aquifer and is thus the only source for replenishing groundwater resources in the area. This general picture of the hydrology of the Río Lurín (Figure 3.1) was drawn from literature and own field visits; further details on the hydrology are presented in Chapter 3.2.



*» **Figure 3.1:** Perceptual model of water resources in the Lurín catchment, which are generated by the rainfall in the upper catchment and infiltration of river water into the aquifer of the lower catchment. Abstraction of water for irrigation from the river and discharge of wastewater into the river occur along the entire length, with the major amounts in the lower catchment.*

About 683 000 people are living in the Lurín catchment, around 674 500 in the lower parts, and around 8 500 in the upper parts. The catchment area comprises thirteen administrative districts (Figure 3.2). Four districts in the lower catchment (Cieneguilla, Lurin, Pachacamac, Villa Maria del Triunfo) belong to the Province of Lima Metropolitana, and nine districts in the upper catchment (Antioquia, Cuenca, Huarochirí, Lahuaytambo, Langa, San Andrés de Tupicocha, San Damian, Santiago de Tuna, Santo Domingo de los Olleros) belong to the Province of Huarochirí.



» *Figure 3.2:*
Map of the Lurín catchment with administrative districts and selected villages.

Still, administrative districts and the hydrological definition of the catchment do match only in part. The district Villa el Salvador, topographically belonging to an intercuenca (blind drainage area), has been considered as additional part of our study area, because around half of its population is supplied with water from the hydrological catchment of Lurín. In contrast, the population of Villa Maria del Triunfo is only partially supplied with water from the Lurin catchment, and the population of Santo Domingo de los Olleros only to a very small degree. In consequence, we included 50 % of the population of the districts Villa el Salvador and Villa Maria del Triunfo, respectively, and 10 % of the population of Santo Domingo de los Olleros into our population count, which we based on census data at district level (INEI, 2018).

Economy in the upper parts is mainly small-scale agriculture on irrigated fields; important crops include potato, wheat, alfalfa, and corn. In addition, there is fruit-growing in the central part of the catchment, and livestock farming and mining of gravel, sand, and clay for building materials in the lower parts. The most important economic sectors in the lower part, however, are the growing industry and increasing tourism from the capital Lima (Alfaro et al., 2010).

The drinking water supply in the upper districts is organized on a decentralized basis. In each village, the facilities for drinking water supply, including springs, wells, elevated tanks, disinfection, and distribution are managed locally (Chapter 4). Around 80 % of the population are connected to distribution systems for drinking water, and about half of the households are connected to a sewer system (own calculations based on INEI, 2018). However, the wastewater then is disposed of without further treatment into the river, which is a risk for subsequent uses.

The lower Lurin catchment area belongs to Lima Metropolitana, where SEDAPAL is formally responsible for the drinking water supply and wastewater disposal. As only about 40 % of the population are connected to the drinking water supply system (INEI, 2020), both, municipal actors as well as private actors (companies distributing water from tank trucks) play a role in parts of these districts. Deep groundwater wells are the main source for drinking water. A central sewer system collects the wastewater of about half of the households. The wastewater is partly treated at the wastewater treatment plants Cieneguilla, Manchay, José Gálvez, San Pedro de Lurín, and Julio C. Tello.

3.2 Water Balance and Hydrology of the Lurín Catchment

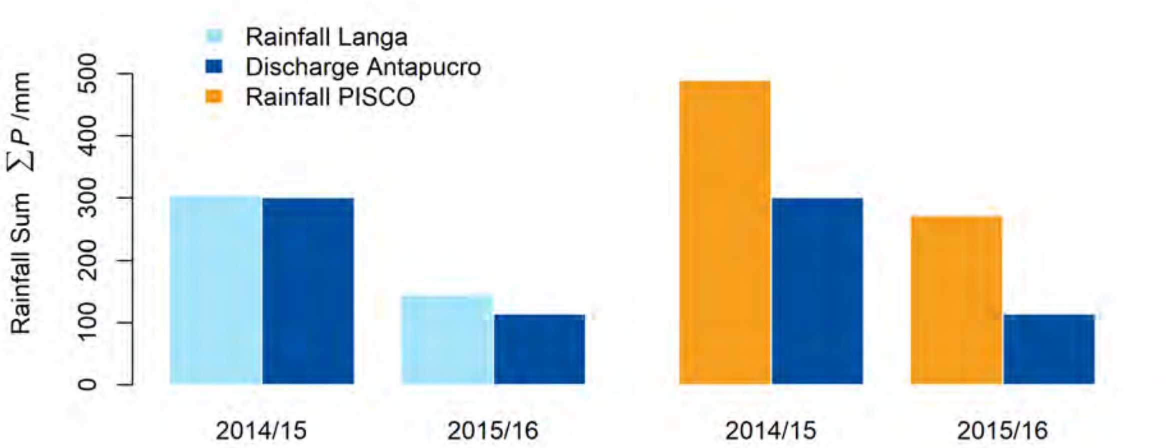
Jan Bondy, Samuel Schroers, Jan Wienhöfer

The water balance of a catchment is defined by the input from precipitation (P) and the outgoing stream flow (Q), as well as evapotranspiration (ET) and possibly changes in the (subsurface) water storage (ΔS). The hydrological processes that convert rainfall into stream flow occur at different scales. Time-variable stream flow Q is measured at a stream gauge at a certain point of the river as a volume per time (e.g., m^3/s). Precipitation P and evapotranspiration ET are processes that are variable in both time and space, and that are affected by the entire contributing area upstream of the stream gauge. These are measured as volume per area and time (e.g., $L/(m^2\ d) = mm/d$).

For the assessment of water balances and discharge dynamics in the Lurín catchment, we collected and analyzed existing data (Chapter 2), set up new monitoring stations, and applied hydrological modelling.

3.2.1 Water Balance Estimations

We started the project with an estimation of the annual water balance for the past two hydrological years with complete rainfall and discharge records (September 2014 to August 2016). We compared the discharge at Antapucro stream gauge (1 047 m asl), first, with the precipitation sum measured at an intermediate-elevation rain gauge (Langa, 3 074 m asl), and secondly, with the areal precipitation from the gridded precipitation data product PISCOp V2.1 (Peruvian Interpolation of the SENAMHI'S Climatological and hydrological data Observations - precipitation; Aybar et al., 2019). The first water balance estimate suggests a runoff coefficient (Q/P) close to unity (Figure 3.3), indicating that almost all rainfall left the catchment as stream flow. However, in a semi-arid tropical region, evapotranspiration is expected to account for a considerably higher percentage of the precipitation, which is better reflected in the water balance based on PISCO (Figure 3.3). A reliable estimate for the rainfall input is thus essential, but despite all auxiliary information that can be used (e.g., radar information, or satellite data as in PISCO), it still relies on the availability of rain gauge data. We thus installed our own rain gauges in the sparsely covered parts of the Lurín catchment, also because the updating scheme of PISCO was unknown. In order to obtain areal estimates of the rainfall input, we developed our own interpolation scheme.



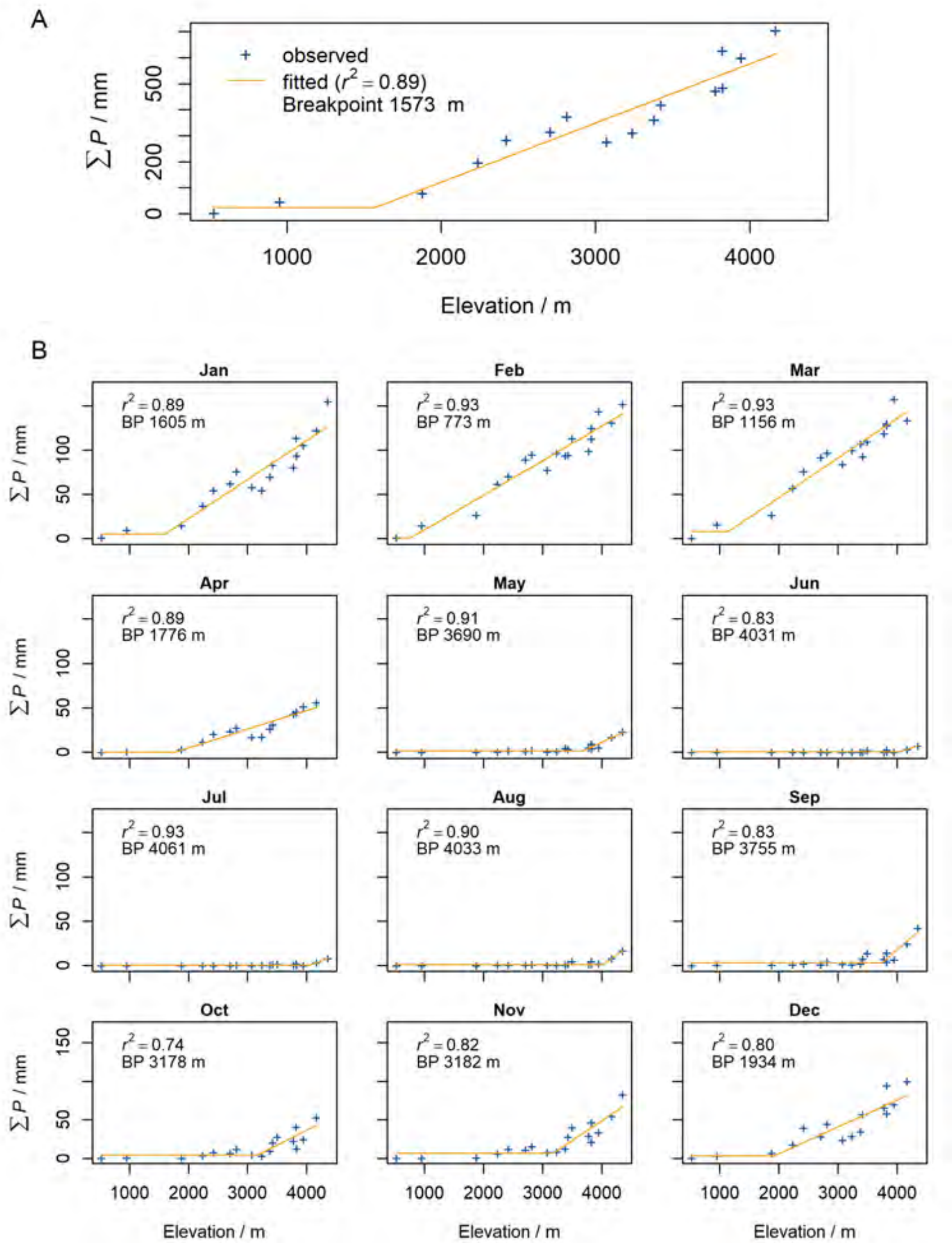
*» **Figure 3.3:** Water balance estimates for the Lurín catchment at the stream gauge Antapucro in the years 2014 to 2016 based on rainfall data from station Langa (left), and rainfall data from the gridded precipitation product PISCO (right).*

3.2.2 Precipitation Interpolation

The three CHIRILU catchments have a similar orientation between the Andean crest and the Pacific Ocean, and therefore offer comparable climate conditions. For our analyses of the precipitation characteristics in the Lurín, we included the meteorological data from the two neighboring catchments to augment the database.

Both at yearly and monthly scales, we found a strong correlation of rainfall and elevation above a certain threshold (Figure 3.4), which was found to be at 1 573 m asl for annual rainfall sums. The threshold shows a seasonal variation, reflecting the variations of the thickness of the inversion layer caused by subsidence in the lower boundary layer of the atmosphere.

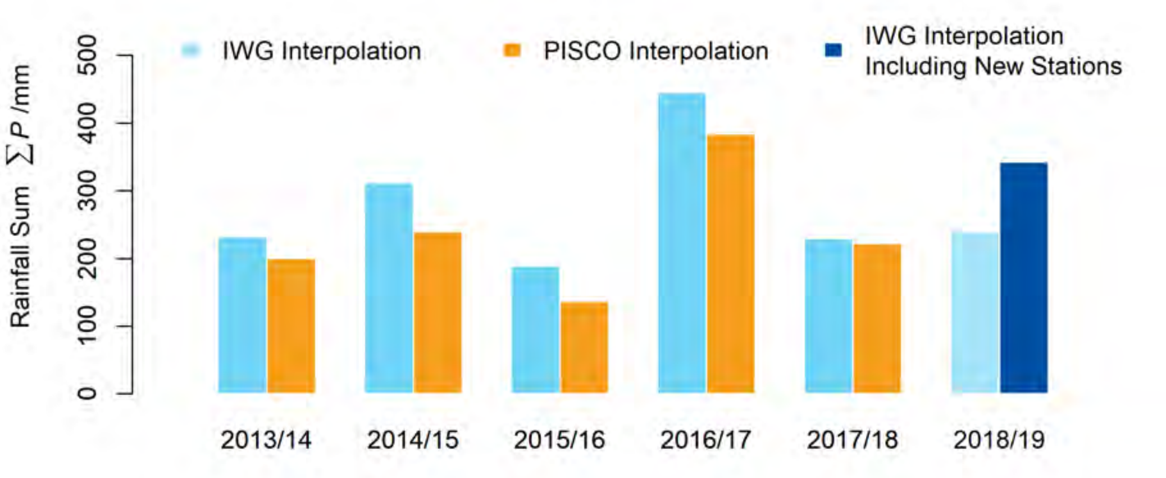
We then analyzed the local deviations of monthly rainfall sums from the elevation-dependent mean. These could not be explained well by the distance between the measurement stations, as shown by a variogram analysis, which is the basis for classical geostatistical Kriging approaches. Instead, the fluctuation correlated with the difference in elevation of the stations.



» *Figure 3.4:*
Correlation of average rainfall sums in the CHIRILU catch-ments with elevation, based on stations with 30 or more years of data: (A) Annual averages of rainfall sum against elevation asl and fitted linear regression, with breakpoint at 1 573 m asl. (B) Same for monthly averages of rainfall sum; BP: breakpoint, r^2: coefficient of determination.

In order to estimate areal precipitation in the Lurín catchment under the prevailing meteorological and topographic conditions, these statistical relationships were used to define an interpolation model that regionalizes the weighted fluctuation around the long-term elevation-dependent mean (Alcamo, 2019). The model estimates monthly precipitation sums for an arbitrary point in the catchment, which can be downscaled to daily values by uniform distribution or distribution to rainy days.

The locally adapted model produces an interpolation that is consistent with the available data. It systemically estimates more rainfall for the catchment area compared to PISCO (Figure 3.5), which appears plausible in view of the discharge data. Having an alternative method for rainfall interpolation became especially useful for the hydrological year of 2018/19, when PISCO data were no longer available. Moreover, the interpolation model allowed including the monitoring stations set up by the TRUST project in 2018 in the highest part of the Lurín catchment. This part of the area has otherwise not been monitored, although here the highest rainfall amounts can be expected. Including these stations in the interpolation model increased the total precipitation estimate by 50 mm/a, compared to the model estimates without the new stations (Figure 3.5). The higher rainfall amounts in the upper part are in line with the expectations from the first water balances (Figure 3.3). With this data on rainfall input, we were prepared to set up hydrological models for the Lurín catchment.



*» **Figure 3.5:** Comparison of rainfall sums for hydrological years interpolated with the IWG model and PISCO for the entire Lurín catchment from 2013 to 2019. In 2018/19, no PISCO data were available, but the new rain gauges. In this year, the results of the interpolation model with and without including the new stations are shown.*

3.2.3 Hydrological Modelling

A hydrological model uses meteorological forcing data (precipitation, and other meteorological parameters) to simulate the discharge at a stream gauge or the outlet of a hydrological catchment. A model potentially allows bringing data coherently together, gaining information about not measured fluxes or fluxes in ungauged sub-areas, as well as the simulation and prediction of potential future scenarios. The behavior of a catchment is modeled in terms of dominant exchange processes and storages. The details of their representation, however, differ considerably between the numerous models and modelling approaches that are used in hydrology. There are either lumped or spatially distributed models, and the underlying approaches can be probabilistic, conceptual, or physically based. The model type and structure determine the type of input data required, and the purposes the model can serve. The parameters of these models often need to be found through calibration, by matching the model output (discharge) to observations. Even if this optimization allows a good fit, it needs to be verified that the resulting parameters represent the system's behavior also in other time periods with different conditions (validation).

For the Lurín catchment, we applied the mesoscale Hydrologic Model (mHM; Samaniego et al. 2010), which is a spatially distributed model that uses a specific parameter regionalization and calibration method. The processes that mHM accounts for include canopy interception, soil moisture dynamics, infiltration, surface runoff, evapotranspiration, subsurface storage and discharge generation, deep percolation and baseflow, as well as flood routing. The model parameters used in the calculations of these processes are regionalized using transfer functions that link the parameters to the catchment characteristics (spatially distributed input data like topography, soil texture, geology, vegetation). Calibration of the model is done on the transfer functions.

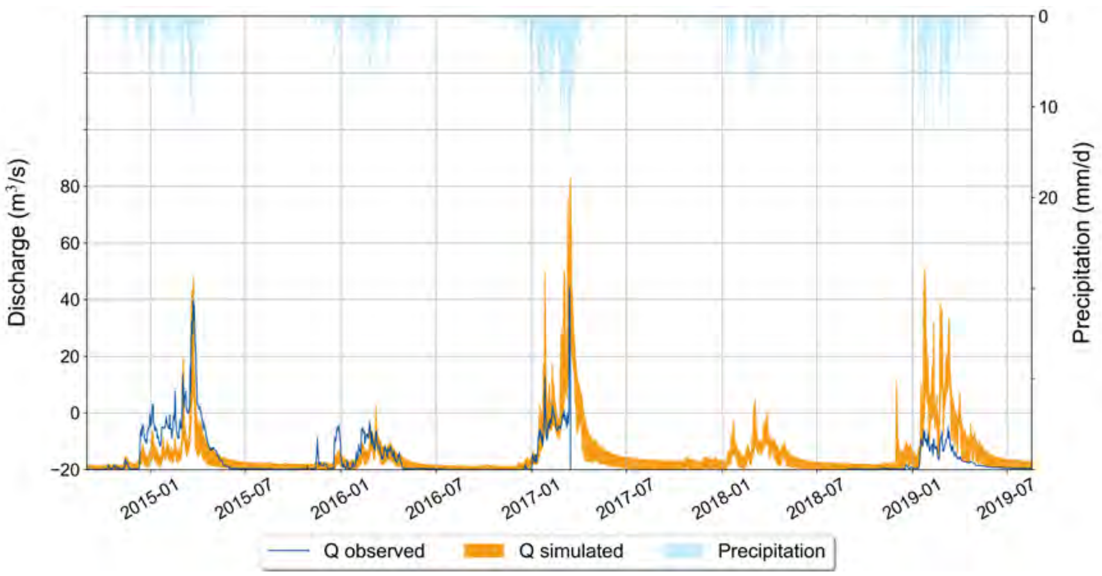
We used the input data collected for the area (Table 3.1) to set up mHM with a grid size of 1 000 m. The Antapucro stream gauge served for calibration, where discharge data were available between August 2014 and March 2017, as well as after August 2018. Different measures for model efficiencies (emphasis on high flows or low flows), and different calibration periods were tested; either calibrating to selected hydrological years, or to the longer time period 2014-2017, which includes around 2.5 hydrological years.

While for individual years a satisfactory match to observed discharge was obtained, the range of simulations shows significant differences in the goodness of the model between the hydrological years (Figure 3.6). This was especially true when calibrating to individual years and validating with others. When calibrating to the longer period, the simulated values tend to underestimate observed discharge in the water year 2015, and overestimate discharge in in the water year 2019. According to monitoring data, the hydrological years show quite different runoff coefficients even with comparable rainfall amounts. Since calibration forces the model to find the best parameters for its calibration period, it cannot account for such differences, but will either find a parameter set that fits the calibration year well and the others worse, or find a parameter set that fits the different years in the calibration period equally to a moderate extent.

Reasons for such differences can be manifold. Most likely, reasons can be found in the discharge data, because the rainfall input data with both PISCO and interpolated station data can be considered as relatively certain in comparison. Another possibility is that in certain years, due to the ENSO phenomenon, the meteorological conditions, such as the predominant type of rainfall events and thus rainfall intensities are different, and not sufficiently captured in the monitoring data. This hypothesis was drawn from findings of a modelling study done at KIT-IWG for the more densely instrumented Chillón catchment, where the calibration/validation of mHM worked less well when including ENSO years (Aybar, 2020).

» *Table 3.1: Overview on input data used for setting up mHM simulations*

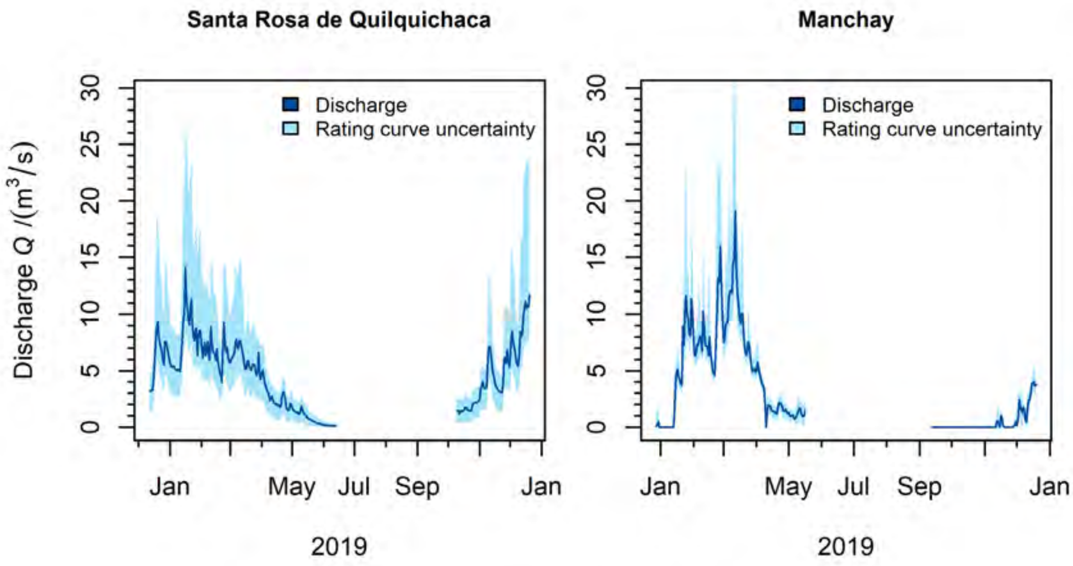
DATA	SOURCE	RESOLUTION	METHOD
Discharge	Stream gauge Antapucro	Daily	Water level and rating curve
Precipitation	1. PISCO product	Daily 0.1°	Combination of satellite and station data
	2. Rain gauge stations	Daily 1 km	KIT-IWG precipitation interpolation
Potential Evapo-transpiration (ETp)	Temperature data from CHIRILU catchments	Daily	Elevation-based temperature regionalization ETp method: Hargreaves-Samani
Soil texture	Soilgrids.org (ISRIC)	250 m	
Leaf Area Index (LAI)	NASA MODIS	Daily 500 m	
(Hydro-)Geology	National GIS map		
Topography/DEM	Tandem-X (DLR)	12 m	



» *Figure 3.6: Rainfall and range of discharges simulated with different calibrations of mHM in comparison with observed discharge at the Antapucro gauge.*

3.2.4 Analyses of Monitoring Data

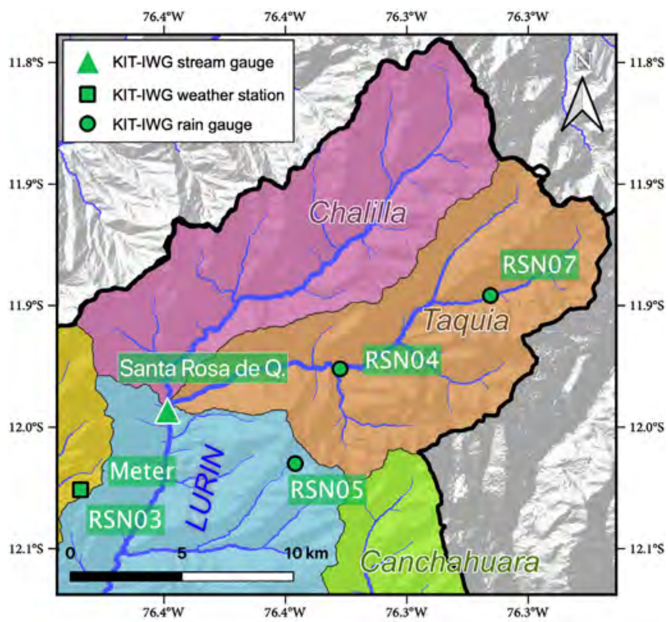
The new stream gauges were installed in the Lurin catchment at locations where the discharge data allow for further analyses of the catchment's hydrology. Discharge measurements of all stations are subject to rating curve uncertainties. The uncertainty is particularly high for water levels not covered by the range of reference measurements (Chapter 2.2.3). For the new stations Manchay and Santa Rosa de Quilquichaca, we can include these uncertainties in our discharge estimates (Figure 3.7), which actually increases the validity of the analyses.



» *Figure 3.7:*
Discharge observations 2019 at KIT-IWG stations Santa Rosa de Quilquichaca (left) and Manchay (right) with range corresponding to rating curve uncertainty.

3.2.4.1 Runoff Generation in the Headwater Catchments

Steep and rugged terrain and only few dirt roads make the Lurín headwater catchments difficult to access for data collection, which is probably one of the reasons for the lack of monitoring data in the past. With the stream gauge Santa Rosa de Quilquichaca at 3 005 m asl, and two rain gauges installed in the connected subcatchment Taquía at 3 680 m and 4 340 m asl, respectively, we have established a promising data source for analyzing hydrological processes of the Lurín headwater catchments (Figure 3.8).

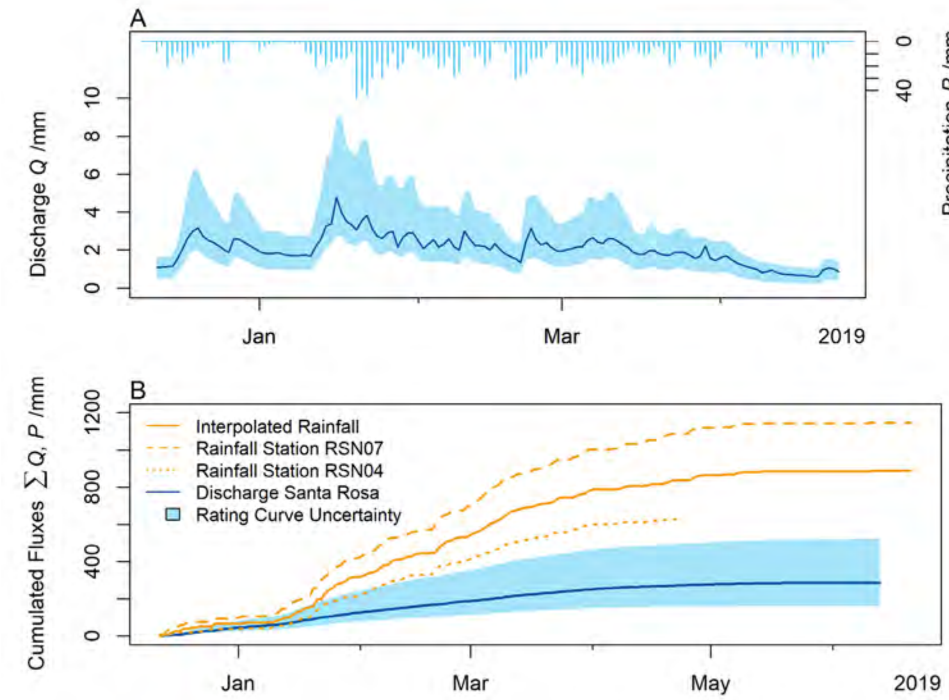


» *Figure 3.8:*
Map of headwater catchments of the Lurín and KIT-IWG monitoring stations installed during the TRUST project.

The first year of rainfall-runoff data (hydrological year 2019) showed generally a rather fast response of discharge to rainfall, which was especially evident at the beginning of the rainy season (Figure 3.9A). The fast response implies that direct runoff through overland flow was the main runoff generation process. The highest discharge peak occurred in mid-January 2019 after continuous, but moderate rainfalls, and thus relatively early in the rainy season. Although even larger rainfall events followed, the resulting discharge peaks were smaller. This is probably the result of gradually increasing infiltration into the subsurface along with the wetting of the soil cover, which increases its hydraulic conductivity. The soils in the Taquía subcatchment were found to be loam soils with high saturated hydraulic conductivity: lab measurements on six soil samples from the upper 30 cm gave saturated hydraulic conductivities around 5×10^{-4} m^{s-1}. These observations make it plausible that infiltration excess dominates runoff generation at the beginning of the rainy season, because the rain cannot penetrate deeply while the soil is dry and features low hydraulic conductivity. Along with the rainfall, soil moisture content and infiltration of rainfall into the soil would also increase, eventually sustaining plant growth (evapotranspiration) beyond the wet season. Water would possibly also start to percolate to greater depths and locally recharge groundwater, which then can feed river base flow and spring flows.

The available data, however, allow some water balance estimates for the hydrological year 2019. We installed the sensors in December 2018 when the rainy season had already started, but overall we captured the season quite completely. Based on our precipitation interpolation, areal rainfall from December to June was about 885 mm for the headwater catchments upstream of Santa Rosa (Figure 3.9B), while 120 mm fell in the three months before the equipment was installed. The measured discharge until June corresponds to 286 mm with the mean rating curve (minimum 160 mm and maximum 522 mm).

Considering only the measured period, this would leave around 600 mm (725 mm to 363 mm) of the rainfall input that were either stored in the soil and used for evapotranspiration (ET), or left the headwater catchments after June as river base flow or as groundwater flow. Our hydrological modelling results (section 3.2.3) indicate that actual ET summed to about 330 mm from December 2018 to August 2019. Base flow at Santa Rosa from June to August was not more than 44 mm to 76 mm. Balancing these figures leaves around 194 to 225 mm (with the mean rating curve) of rainfall that are not accounted for. This water could have left the headwater catchments underground, feeding the springs in the upper catchment area and the river further downstream. As the estimates for P, Q, and especially ET are subject to uncertainty, further research is needed to verify and quantify the runoff generation and the water balance in detail.



» ***Figure 3.9:*** *Monitoring data from the Lurín headwater catch-ments include discharge at Santa Rosa de Quilquichaca and rainfall from two stations in the Taquía subcat-chment (255 km²): (A) daily discharge and maximum daily precipitation from 2018-12-12 to 2019-04-24 (normalized per area); (B) cumulated fluxes of rainfall from stations and interpolation model, as well as discharge with rating curve uncertainty, from 2018-12-12 to 2019-06-21.*

3.2.4.2 Infiltration of River Water into the Lowland Aquifer and Drainage to the Ocean

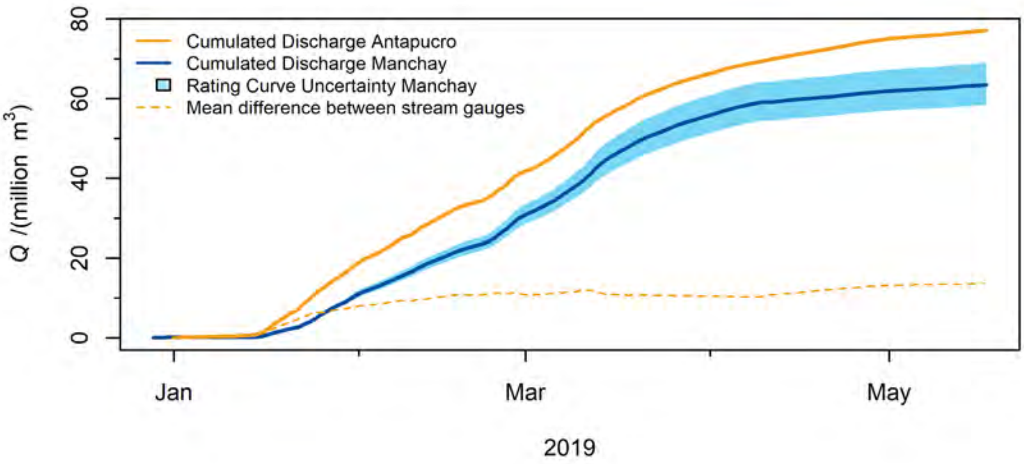
The lower part of the Lurín catchment receives barely no precipitation. The water resources in this part of the catchment are completely fed by the river water of the Lurín. Water is either extracted directly by channels from the river, or, largely, from the groundwater of the valley bottom aquifer, which is recharged solely by river water stemming from the higher parts. Besides the groundwater wells run by SEDAPAL, a large, yet not exactly known number of private wells are also exploiting the groundwater from the Lurín valley aquifer. With the discharge measurements in Antapucro and Manchay it is now possible to estimate the amount of runoff infiltrating between the two gauges, and thus the groundwater renewal rate that determines the amount of sustainable groundwater use. The difference of discharge between Antapucro and Manchay was assessed including the uncertainty range of the Manchay rating curve (Figure 3.7). For the Antapucro stream gauge, this uncertainty could not be assessed.

For the months of January to May 2019, which is the period from installation of the gauge Manchay to the end of the rainy season, we estimate that around 63.4 million m^3 (between 58.4 to 69.0 million m^3) were flowing past the stream gauge Manchay. The volume at the gauge Antapucro, which is located 29 km upstream, equaled 77.1 million m^3 during this period (Figure 3.10). The difference of 13.7 (8.1 to 18.7) million m^3 is the amount of water that has infiltrated into the valley bottom aquifer. These numbers would also include additional flows like abstractions from the river for irrigation, which have not been included in this preliminary analysis for lack of quantitative information. The only additional inflow found during site visits was the effluent of the Cieneguilla wastewater treatment plant, which can add less than an estimated 0.1 m^3/s at maximum flow. Probably, these additional flows in sum are relatively minor compared to the infiltration.

The main part of the season's rainfall and runoff occurred during the observed period (compare 3.2.4.1). Therefore, we can take the result as a rough estimate for the hydrological year 2019. The groundwater recharge from the Lurín between the two gauges is likely to continue throughout the year, but amounts will be substantially lower towards the end of the dry season. With about 8 to 19 million m^3, the figures fit well with the estimate for sustainable groundwater withdrawal from the Lurín aquifer of about 15 million m^3 per year (Coronel, 2012; Observatorio del Agua Chillón Rímac Lurín, 2019). The possibility of measuring the infiltration amount with stream gauges will help to substantiate the information on groundwater recharge in the future, and thus facilitate sustainable management of groundwater extraction. Continuing the observations on a long-term basis will help to understand the variability between different years, and potential trends due to climate or land-use changes.

The drainage of the basin to the ocean can also be inferred from the measured discharge. Further infiltration from the Lurín downstream of Manchay is probably less than upstream, as suggested by site visits during the dry season. For a conservative estimate, we can still assume a similar loss rate for the remaining 16 km to the Pacific Ocean as observed for the reach between Antapucro and Manchay, which was found to be around 0.47 million m^3/km (0.64 to 0.28 million m^3/km) during the period considered. This would result in further infiltration losses of up to 7.6 million m^3 (10.3 to 4.5 million m^3), and would leave around 55 (48 to 64) million m^3 of river water that have drained from the Lurín catchment to the Pacific Ocean during this period.

» *Figure 3.10: Cumulated discharge volumes measured at Antapucro (upstream) and Manchay (downstream) between 2018-12-28 and 2019-05-17. The difference in volume allows an estimation of the groundwater recharge by infiltration into the valley bottom aquifer between the two stream gauges, while the observation at Manchay additionally allows assessing the volume of water that drains to the Pacific Ocean.*



3.2.5 Increasing the Availability of Water Resources

Making (parts of) the 55 million m³ of water available for usage would require to take a combination of measures that help retaining the water within the catchment that would otherwise drain into the ocean. The aim would be to increase baseflow and delay discharge dynamics. This could be achieved by fostering infiltration into soils in the upper catchment on a large scale, for example by reactivating and extending the amunas, an indigenous infiltration enhancement system (Ochoa-Tocachi et al., 2019). Other measures could include fostering infiltration into the groundwater aquifer in the lower catchment, and water storage in additional reservoirs in the upper catchment (see also 3.4. for an overview on measures and instruments). Further investigations in the catchment are needed to quantify the local effects of these measures and to support their planning and design, as for example the assessment of possible ecological impacts of new measures, or the quantification of evaporation losses from reservoirs. A continuously operated and maintained monitoring network is in any case an essential part of an integrated water resources management.

This also extends to monitoring of groundwater resources, which were not assessed by the TRUST project. Still, groundwater constitutes a major part of the water extraction in the catchment, and needs to be considered as well for a complete balance. It is known, also from earlier studies (Coronel, 2012), that the aquifer in the lower Lurín valley is solely fed by infiltration of river water. While the amount of infiltration can be estimated with the help of the stream gauges located before and after the infiltration zone, the extraction amounts by the over thousand official and unofficial wells do remain uncertain. There is concern that the current groundwater extraction exceeds the sustainable withdrawal amount by far, meaning that shallow wells are likely to fall dry, and groundwater from coastal wells will increase in salinity. Controlling and regulating the extracted groundwater quantities seems mandatory; the stream gauges at the borders of the main infiltration zone can help in specifying the sustainable withdrawal amounts. In addition, enhancing groundwater recharge from river water and water re-use can be options to help further attenuating this decline in groundwater volume.

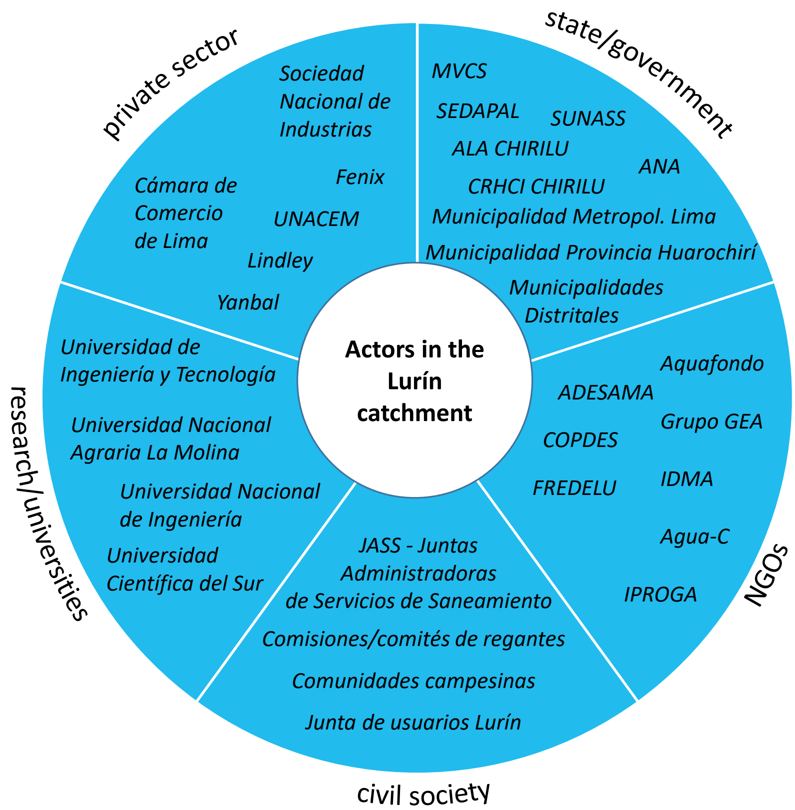
3.3 Actors and Governance

Christian D. León, Yvonne Zahumensky, Fabienne Minn, Hannah Kosow

The Lurín catchment area includes four districts of the Province of Lima Metropolitana, and nine districts of the Huarochirí Province (see Figure 3.2). Consequently, one can find a number of relevant actors with common and/or competing interests operating on a variety of spatial scales along the Lurín river valley. They show a complex network of diverse relationships. Some of these relationships are strong, some are weak; some have grown for a long time and are strengthening; others have been disrupted due to disagreements; and still others are yet to emerge as actors change and new actors enter the scene, changing the powers to influence decision-making.

In the TRUST project, we defined relevant actors as stakeholders (individuals, groups or organizations), who have an interest, may affect or be affected by concepts or policies regarding integrated water resources management in the Lurín catchment. A detailed and comprehensive analysis of all relevant actors can be conceived as an actors' landscape. It provides the basis for a holistic understanding of the interrelationships between actors, their goals, interests and positioning in drinking water and wastewater management. In order to provide an overview on the wealth of information, we have visualized this actors' landscape in form of "maps" that facilitate an easy and quick understanding of the complex dynamics of actors' networks in the project region (Chapter 4.2.1).

The actors' landscape in the Lurín catchment is complex because it includes actors from various sectors, including state, private, and civil society actors, and at different scales, i.e., from the local to the national level (Figure 3.11).



» *Figure 3.11: Overview on the actor landscape of the Lurín catchment (selection of central actors; see list of abbreviations).*

1. State/governmental actors (national, regional, local level)
    - Ministries and relevant authorities
    - Regional and local governments as well as administrations
    - Important management councils and semi-public service providers
2. Non-governmental organizations
    - NGOs with regional competence in water issues
3. Civil society actors
    - Peasant communities (Comunidades campesinas)
    - Communal water organizations (JASS)
    - Irrigations committees (Comisiones/Comités de regantes)
    - Lurín water user associations (Junta de usuarios Lurín)
4. Research organizations and universities
    - Public and private universities
    - Other relevant research organizations
5. Private sector actors
    - Industries (energy, textile, food, hygiene, construction, chemistry, oil, ceramics, plastics, medicine)
    - Mining
    - Chambers of Commerce and other interest committees

All relevant actors in the catchment area of the Río Lurín were described individually in an internal report. This report contains information on objectives, projects and activities of the actors in the catchment area, and served as a reference for the project partners. The report has been continuously updated.

The stakeholder setting and the resulting institutional framework in the water sector of Lima Metropolitana have already been described as complex and challenging (Schütze et al., 2019). Officially, the National Water Act (Ley de Recursos Hídricos No. 29338) of 2009 is supposed to regulate the roles and responsibilities of the various actors. Effectively, there is a fragmentation of state, private sector and civil society actors. Some do not cooperate, others do not even know about each other.

More specifically, the following observations can be made: Different actors are responsible for the various water sectors (drinking water, irrigation water, industrial water, wastewater, hydropower, ecosystems). Since these are not sufficiently interlinked, there is a potential for conflicting interests in the use of the same water resources. Such conflicts may occur within the catchment area, between parts of the catchment area or even within single entities.

Conflicts within single entities mainly occur in organizations with multiple tasks, e.g., drinking water supply and sanitation responsibilities. Due to the difficult accessibility of communities in the upper catchment area and due to their traditional self-administration, state regulatory authorities are mainly focused on the lower catchment area. As a result, there are no or hardly any state-controlled water management activities in the upper catchment area.

The water sector in the upper catchment area is organized in self-administration and follows traditionally grown structures, whose routines and rules are locally specific and not easily comprehensible for outsiders. The traditional local water management bodies in the upper catchment area are civil society entities that perform public tasks, often lacking human and financial resources and sometimes also knowledge and prestige. Local authorities may devolve the communal water management practice and monitoring to civil society organizations that may vary in their degree of formality, but are historically rooted and socially accepted. Implementing national (often unpopular) regulations, thus, sometimes appears challenging or impossible due to the double and at times contradictory mandates and roles of such hybrid actors, who act as both civil organizations and as public service provider. There is a considerable gap between the legally applicable regulations and their actual implementation. This results in little effective control and monitoring. Intercommunal cooperation between the municipalities of the upper catchment area exists formally, but is not always as intensive as it should. Multi-actor platforms such as the CRHCI CHIRILU (see below) are currently in the initial stages of their work, and some sectors, first of all the private sector, are still underrepresented. Relevant key actors are briefly described below.

Local Water Authority (ALA CHIRILU - Administración Local del Agua)

The ALA (Administración Local del Agua) is the lowest decentral administration entity of the ANA (Autoridad Nacional del Agua) on the local level. ALA CHIRILU (ALA that touches the catchments of rivers Chillón, Rímac and Lurín) is one of five subordinated units of the AAA (Autoridad Administrativa del Agua) Cañete-Fortaleza. ALA CHIRILU has a high level of interest and knowledge on water management and has conducted various studies on the hydrological situation of aquifers and surface waters. However, the influence of ALA in the upper catchment area is limited; it has more influence in the lower area.

Water Resources Council CHIRILU (CRHCI - Consejo de Recursos Hídricos de Cuenca Interregional)

The Water Resources Councils (CRHC) are organs of the ANA. They are functioning as institutional dialogue spaces of specific water catchment areas on the base of the National Water Act No. 29338.

Through the council, important stakeholders from the water sector are offered a space for discussing regional water related problems, reaching agreements and commitments to planning, coordinating and implementing joint measures for the whole catchment area in an integrated way. The overall aim is the implementation of an integrated water resources management (IWRM) in the three Chillón, Rímac and Lurín catchments.

The ANA and the governments of the Lima Region, Lima Metropolitana and Callao Region are especially committed to the foundation of the Consejo de Recursos Hídricos de Cuenca Interregional Chillón Rímac Lurín (CRHCI CHIRILU). Since the catchments differ in their structures and uses, some actors call for one separate council for each catchment: in contrast to the Rímac and Chillón catchments, there is still a significant amount of agricultural activity in the middle and lower catchment area of the Lurín valley. Furthermore, the Río Lurín is not regulated by large artificial reservoirs in the upper part of the catchment, as in the Río Chillón and Río Rímac. To address the complaints of these actors, a specific working group for the Lurín catchment (Grupo de Trabajo Multisectorial de la Cuenca del Río Lurín) has been installed in October 2018. A second relevant working group of the CRHCI CHIRILU is the “Observatorio del Agua Chillón Rímac Lurín”, a public-private platform that collects and provides data, information, and knowledge on water resources in the river catchments of Chillón, Rímac and Lurín.

So far – and in theory – the CRHCI CHIRILU can be considered a useful and necessary body for an integrated water resources management of the Lurín valley. In practice, since its creation in 2016, it took up its work slowly and with less intensity than expected or hoped for.

SEDAPAL

SEDAPAL S.A. is the state water supply and sanitation company (Servicio de Agua Potable y Alcantarillado de Lima S.A.) for urban settlement areas in Lima Metropolitana and Callao. In addition to drinking water supply and wastewater treatment and disposal, SEDAPAL implements several important projects around the topics of water retention, water quality, protection of ecosystems, and adaptation to climate change, among others. The influence of SEDAPAL is concentrated in the lower part of the catchment; in the upper and middle parts, the role of SEDAPAL is smaller. Despite its lower importance in the upper part, in recent years, SEDAPAL's activities related to ecosystem service focus more and more on the upper part, where water retention mainly happens.

With the population growth and the increase in industrial activities in the lower Lurín catchment, the demand for drinking water as well as water for industry and irrigation has increased, resulting in rising competition among users. SEDAPAL is and will be challenged to coordinate its activities with actors of the upper catchment, to implement an integrated water management strategy that considers the social and natural interdependencies of the lower (rather water consuming) and upper (rather water producing) parts.

JASS – Juntas Administradoras de Servicios de Saneamiento

JASS are non-for-profit, community-managed service providers for drinking water and sanitation that act independently from public and private organizations (Calzada et al., 2017). The particularity of communal organizations is based, among other things, on long historical traditions of self-government and communal work (faenas). Moreover, the Peruvian law provides for the possibility that the local governments responsible for water and sanitation services may entrust the operation and management of water services to the local JASS established for this purpose (MVCS, 2016). Peruvian JASS play an important role by providing water services for more than 3 million people in the country (cf. Calzada et al., 2017: 400). The task of JASS is to provide (waste) water services for the population in small villages. This includes the construction of water reservoirs and management of water systems, e.g., by determining and administrating a monthly water tariff („cuota familiar") as well as convoking communal work (cf. Calzada et al., 2017: 415 f.). The users of the water services are members of the organization, constitute its assembly, elect the board of directors, and hold the power in decision-making. The board of directors consists of elected volunteers, who schedule and control the necessary tasks for the provision of water services. Since the water supply of the population is anchored in the responsibility of the municipalities, the JASS are also supervised and supported in their functioning by the municipal technical area for water and sanitation (Área Técnica Municipal para la gestión de los servicios de agua y saneamiento ATM).

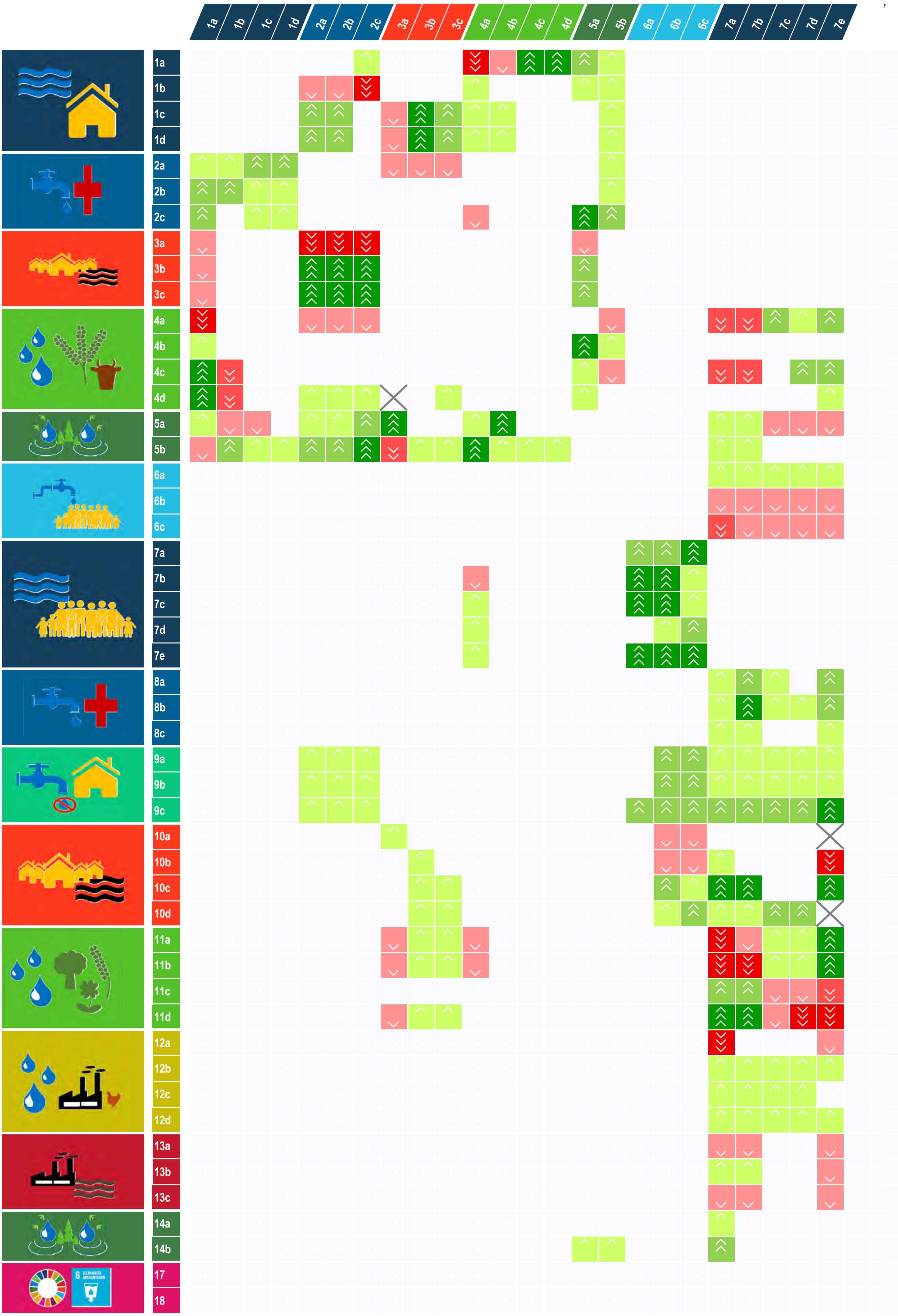
In sum, the above mentioned key actors and governance conditions constitute the background to understand the water use conflicts in the project region. These conflicts are described in the following.

3.4 Consistent Policy Mixes to Overcome Water Use Conflicts

Hannah Kosow

The Lurín catchment is characterized by a profound conflict line between rural and urban realities. This classical conflict does not only separate the rural upper and the urban lower catchment part, but also leads to tensions within the lower part, where agriculture still remains active but is increasingly challenged by urban sprawl (see also Zuchetti & Chirinos, 2001). Figure 3.12 shows the interactions that were identified between alternative policy tools (n = 47) to reach the different objectives (n = 14) of different water users in the upper catchment (upper left quadrant) and in the lower catchment (lower right quadrant) as well as interactions between policies in the upper and lower catchment.

The cross-impact (CI) matrix represents a conceptual policy-interaction model for the entire Lurín catchment (the methods are described in chapter 2.4). The analysis (Kosow et al., 2020a, b) of (potentially) conflicting objectives of the different water users on the level of policies to reach these objectives shows the (latent) prevalence of classical water use conflicts regarding water quantity and water quality. First, there is a competitive use of surface and/or ground water by different users such as households, agriculture and industry (water quantity conflicts). In the upper catchment, the status quo policy mix (Figure 3.13) consists in the joint but competitive use of reservoirs for drinking water and agriculture. In the lower catchment, all major users use groundwater as the main source for drinking water, irrigation water and process water. Second, there is insufficient treatment and/ or insecure disposal of domestic and industrial wastewaters threatening the quality of surface and groundwater sources and thus also potential resources for safe drinking water provision (water quality conflicts). The current policy mix (Mix S 'Status quo") thus is neither effective to fulfill the water related objectives of all water users in the medium and long term, nor is it sustainable in terms of SDG 6 attainment (cf. also Figure 3.14 and Figure 3.15).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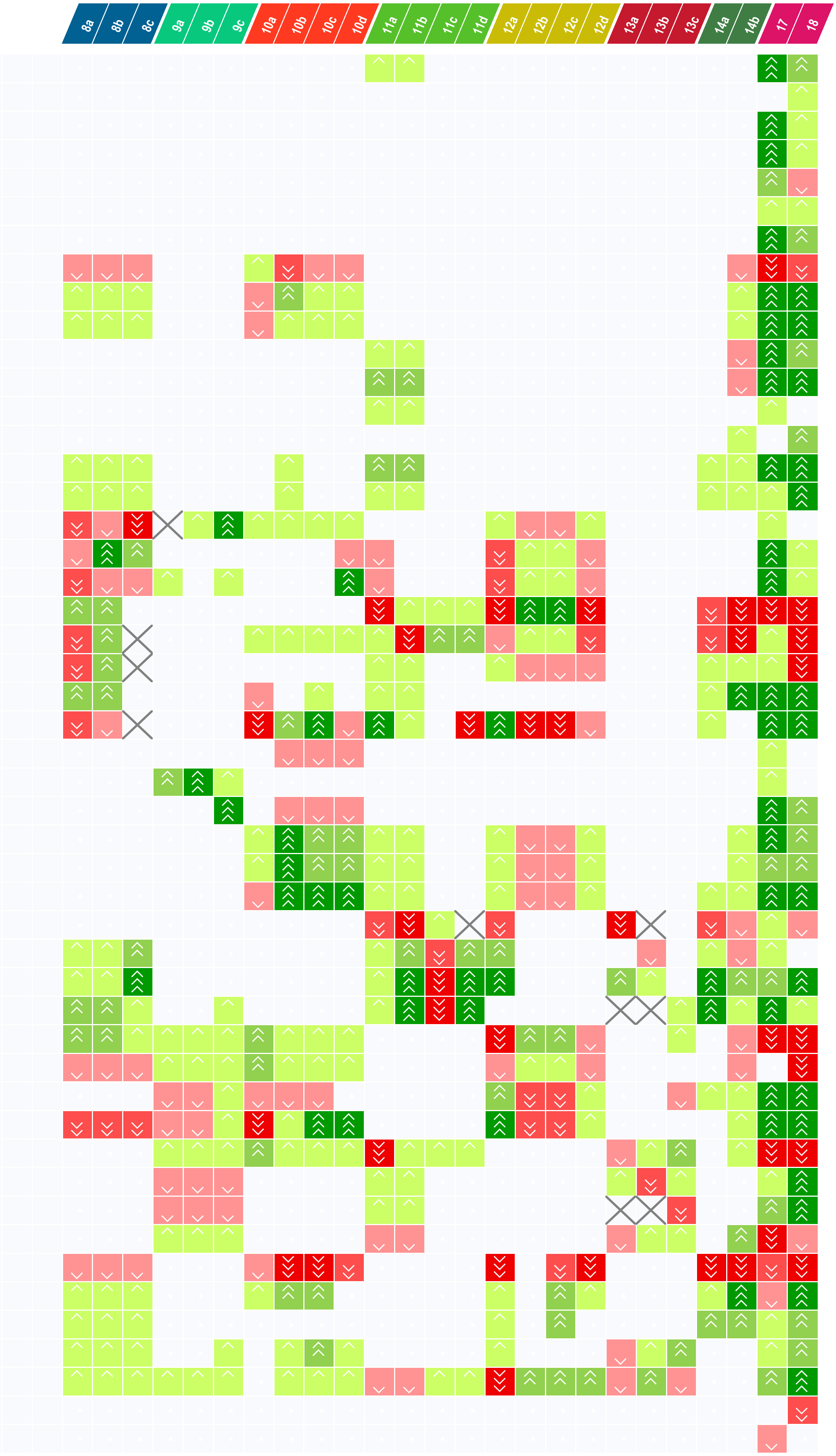
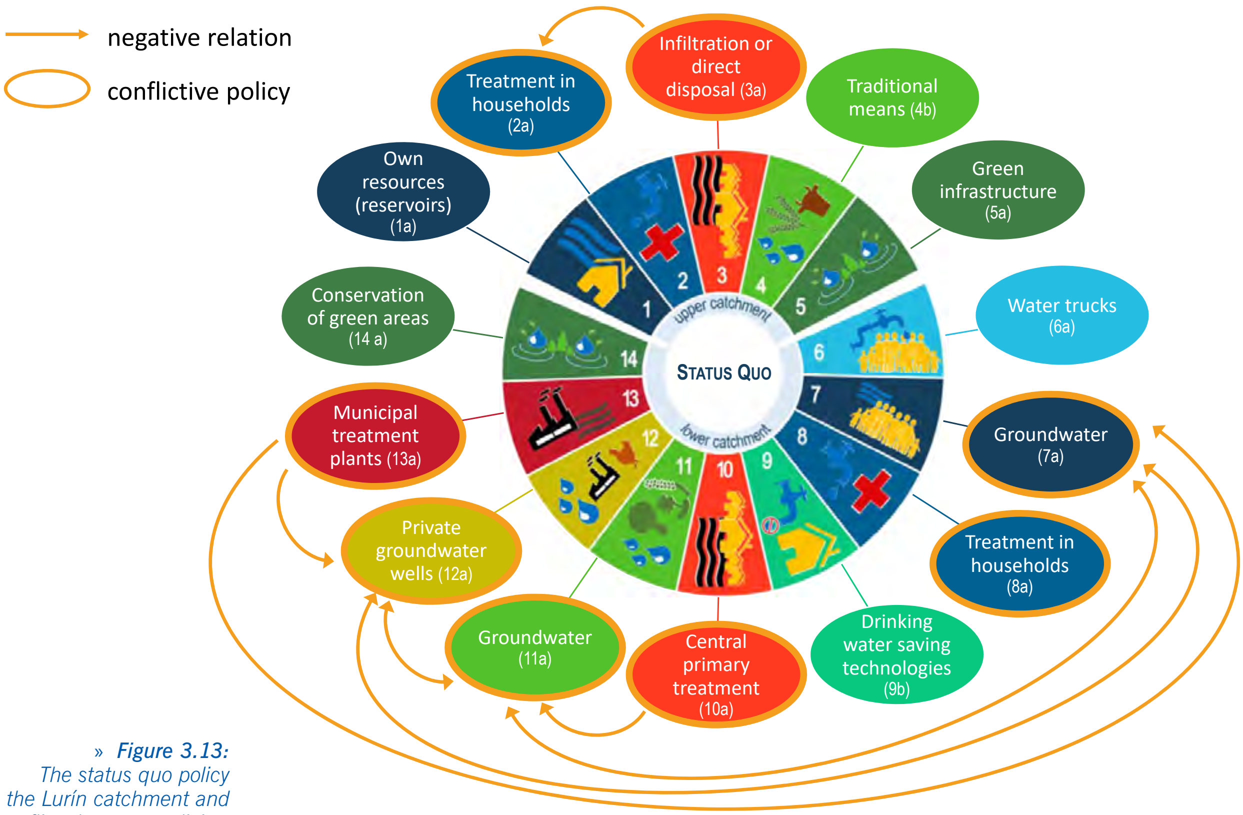


» *Figure 3.12:*
Policy interaction model for the Lurín catchment (CI matrix, visualization inspired by Weitz et al., 2019).



» *Figure 3.13: The status quo policy mix in the Lurín catchment and main conflicts between policies.*

In addition, our analysis also shows that the implementation of new policy solutions may at the same time introduce new conflicting situations. These are, for instance:

- A competitive (re)use of treated wastewaters by different users (e.g., irrigation, aquifer recharge, or industrial processes);
- A competitive use of river water: Accelerated infiltration into groundwater through filtering galleries (galerias filtrantes) to augment quantities available for domestic use as proposed by the water supply company SEDAPAL, or direct use of river water for irrigation, as required by farmers;
- The transfer of water (i.e., of reservoir water in the upper catchment and - treated - river water in the lower catchment) transforms the conflict regarding a competitive use of water resources between users (as agriculture, households, industry) from an internal conflict within the Lurín basin to a cross-basin conflict between users in the Lurín basin and users of the providing river basin.

Applying Cross Impact Balance Analysis (CIB; Weimer-Jehle, 2006) in the Río Lurín catchment shows that around 500 out of 14.9 million hypothetical policy mixes are effective to jointly reach the different objectives of the different users, avoid contradictions between policies, make use of synergies – and contribute to attaining SDG 6. Table 3.2 shows a selection of four policy mixes that represent these solutions while being maximally diverse and internally consistent. Every selected individual policy in a mix is assumed to be mainly or primarily (but not exclusively) used in that mix.

» Table 3.2:
Overview of four selected policy mixes that fulfill the water related objectives of all water users in the Lurín catchment (diversity sampling). For some objectives, two policies are equally consistent choices; the ones not chosen for further assessments are put in brackets.

MIX / OBJECTIVE	A 'RESPONSIBLE (RE-)USE'	B 'MEASURE AND RECHARGE'	C 'TRADITION AND MODERNITY'	D 'MINIMAL CHANGE'
UPPER LURÍN CATCHMENT				
1 Ensure sufficient drinking water for the supply of households and tourists (quantity)	**1d** Water saving technologies	**1c** Water metering and tariffs	**1d** Water saving technology	**1a** Own resources (including reservoirs)
2 Ensure the quality of the drinking water for health protection (quality)	**2b** Central drinking water treatment	**2a** Treatment in households (OR **2b** Central drinking)	**2c** Prevention of contamination (local)	
3 Safe treatment and disposal of domestic and commercial wastewater (municipal wastewater)	**3c** Treatment by separation of material flows	**3b** Central wastewater treatment		**3a** Infiltration or direct disposal (Status quo)
4 Ensure sufficient water availability to expand the agricultural areas	**4d** Reuse of treated wastewater	**4c** Increasing water efficiency	**4b** Traditional means (Andenes, Cochas etc.)	**4c** Increasing water efficiency
5 Long-term conservation of water-related ecosystems	**5a** Green infrastructure			
LOWER LURÍN CATCHMENT				
6 Ensure the access and the distribution of drinking water for the growing population in the lower catchment	**6b** Public drinking water and wastewater network (OR **6c** Local drinking water and wastewater network)	**6c** Local drinking water and wastewater network		**6a** Water truck (OR **6c** Local drinking water and wastewater network)
7 Ensure sufficient drinking water to supply the growing population in the lower catchment (quantity)	**7a** Groundwater (OR 7b River water)	**7e** Managed artificial groundwater recharge (MAR)	**7d** Unconventional alternatives (desalination or treatment of wastewater on drinking water level)	**7a** Groundwater (OR **7b** River water)
8 Ensure the quality of the drinking water for health protection (quality).	**8b** Central drinking water treatment (on the level of wells)			
9 Reasonable and save drinking water consumption	**9b** Water saving technologies (households)	**9a** Water metering and tariffs	**9c** Water culture and behavioral change	
10 Safe treatment and disposal of municipal wastewater	**10c** Central tertiary treatment (OR **10d** Decentralized treatment with multiple use)	**10c** Central tertiary treatment	**10d** Decentralized treatment with multiple use	**10c** Central tertiary treatment
11 Ensure sufficient water for irrigation in agriculture and of green areas	**11d** Reuse of treated wastewater	**11a** Groundwater	**11b** River water (surface water)	**11d** Reuse of treated wastewater
12 Ensure sufficient process water for the (agro-) indust-	**12c** Treated wastewater (multiple use)			**12a** Groundwater
13 Safe treatment and disposal of industrial wastewater	**13c** Decentralized treatment and direct discharge into the river or the ocean			**13b** Internal pretreatment and indirect discharge
14 Long-term conservation of water-related ecosystems	**14b** Regulation of water resources (protected areas and regulation of extractions)	**14a** Conservation of green areas		

Overall, all consistent and synergetic mixes require that in the lower catchment part drinking water quality is assured by disinfection of the groundwater (either at the extraction well or centrally) as a safety measure with respect to possible contamination in the distribution networks and to prevent local contaminations. Additionally, municipal and industrial wastewaters need to be safely treated and disposed of. In the upper catchment, solutions are more diverse.

In mix A “responsible (re)use”, households in the entire catchment are saving water through the use of water saving technologies. In addition, domestic and industrial wastewaters are not only safely treated and disposed of but also reused for irrigation in agriculture in the upper and lower catchment as well as by the industry in the lower catchment. This allows using the existing groundwater resources as drinking water for households.

In mix B “measure and recharge”, the objectives of all water users in Lurín are met because domestic water consumption is controlled by water meters and charged by tariffs in the entire catchment. Furthermore, artificial aquifer recharge (AAR) supports the availability of sufficient water quantities in the lower catchment.

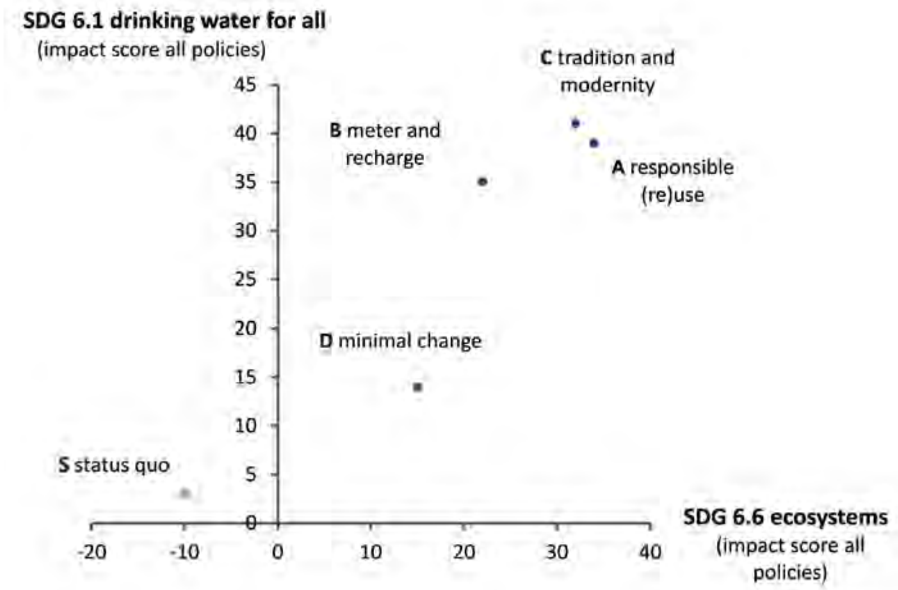
In mix C “tradition and modernity”, in the upper catchment traditional methods of water storage for irrigation (e.g., andenes, i.e., terraces; and cochas, i.e., small artificial and natural lakes to store rainwater) are combined with measures of green infrastructure (as reforestation etc.) for conservation of water-related ecosystems. In the lower catchment, alternative approaches to supply the growing population are implemented, either through water transfers from other catchments or through seawater desalination.

In mix D “minimal change”, 9 out of 14 policies remain close to status quo. The agricultural water users apply efficient irrigation techniques and channels (upper catchment) and reuse treated wastewaters (lower catchment). This allows industry and households to continue using groundwater for satisfying their needs.

These mixes can be further assessed with CIB. Figure 3.14 shows the contribution of the different policy mixes to attain SDG 6 regarding the Lurín catchment; Figure 3.15 shows how synergy gains of different policy mixes are distributed between the upper and lower part of the catchment. To measure their contribution to SDG 6, individual policies have been assessed using criteria closely related to two SDG 6 targets:

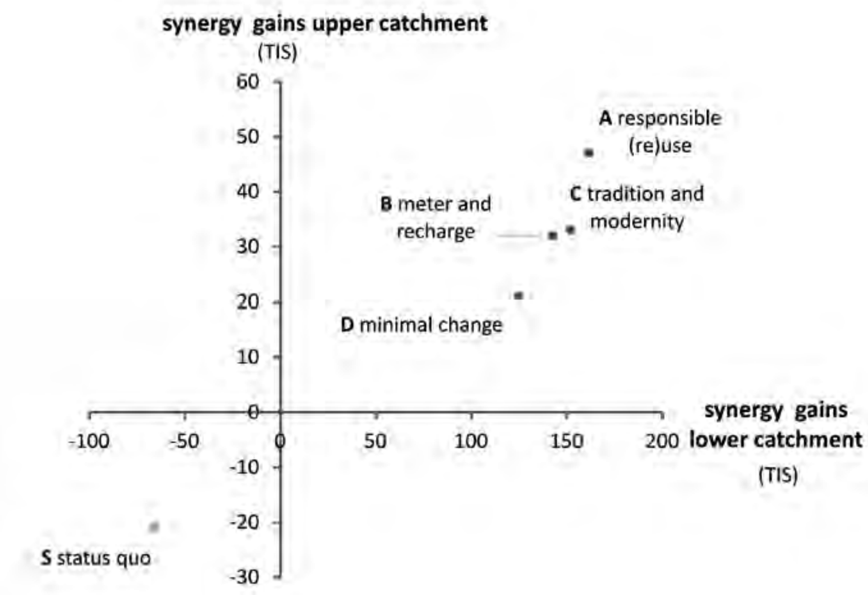
- 6.1 Drinking water for all in Lurín: By 2030, achieve universal access to safe drinking water for all in the catchment of the river Lurín.
- 6.6 Water related ecosystems of Lurín: By 2030, protect and restore water-related ecosystems in the catchment of the river Lurín, including mountains, forests, wetlands, rivers and aquifers, and also natural and artificial lakes and reservoirs in the upper catchment as well as hills and wetlands in the lower catchment.

To assess the sustainability performance of different mixes, we count the net value of impacts of chosen policies of a certain mix onto the two SDG targets. This allows assessing how different mixes support the attainment of these individual targets.



» Figure 3.14: Contribution of different policy mixes to SDG 6 targets 6.1 and 6.6 (impact score: sum of impacts of all policies of each mix on SDG 6 targets).

We measure synergy of policy mixes by using the TIS (total impact score) of CIB. The TIS counts the net value of all impacts (i.e., cross-objective supports and conflicts) activated between the chosen policies of a certain mix. To compare synergy gains between the upper and the lower catchment, the total impact score is split in two parts, each counting all impacts in the upper vs. the lower catchment. It allows assessing, which part of the catchment benefits (more) from the synergies between policies that are generated by specific policy mixes. Both assessments also show how all internally consistent and synergetic policy mixes outperform the status quo.



» Figure 3.15: Synergy gains of different policy mixes in the upper and lower catchment (TIS Total Impact Score: net value of all activated impacts between the chosen policies of a certain mix).

These internally consistent and synergetic mixes are optimal for the achievement of several, equally weighted goals. While they - theoretically - solve goal conflicts, they do not solve distributional conflicts in practice, as for example the question, how users distribute the burden to change policies from the status quo. This political question needs to be dealt with by the local actors in the Lurín catchment.

The mixes served as input into a stakeholder dialogue organized in November 2019 to discuss next steps: What needs to be done to implement these policy mixes, and by whom? The participating actors perceived the integrative perspective of the mixes - on the upper and lower parts of the catchment and considering all water users - as a clear benefit. The alternative policy mixes were seen as a useful starting point for integrated planning processes of local actors and as potential contribution to the water resources management plan of the Lurín catchment in the future.

In sum, in a process iterating between desk research and stakeholder involvement, our methodology was useful to design possible alternative policy mixes for the entire Lurín catchment area that contribute to reduce goal conflicts, to meet the needs of all water users and to attain SDG 6.1 and 6.6.

3.5 Interim Conclusions Entire Lurín Catchment

The upper and lower parts of the Lurín catchment differ in physiographic, organizational and social aspects. Rainfall that is feeding water resources is limited to the upper parts, while the majority of water users live in the lower parts.

Balancing water resources and water use requires to keep the entire catchment area in focus, and to coordinate between actors in the upper and lower catchment areas. This applies to planning of possible management options for increasing water availability, which would include measures to retain water (by enhanced infiltration, or reservoirs) in the upper catchment area to sustain river water flow, and measures to enrich groundwater in the lower parts. This also applies to strategic planning of water use, considering competing uses and goal conflicts between different user groups as well as trade-offs and synergies between policies.

The water use patterns and the related challenges for water supply also differ significantly within the Lurín catchment. In the upper, rural part, irrigation agriculture uses the largest share of water, which is supplied from small man-made reservoirs. In the lower, urban catchment area, mainly groundwater is used for drinking water, irrigation of agricultural and green areas, and industry. Accordingly, the upper and lower parts of the Lurín catchment each show a specific organization of water management and typical governance structures. In our further analysis we therefore examined both the upper and the lower part separately in greater detail. Water supply and wastewater treatment in a rural community in the upper catchment is presented in Chapter 4, while Chapter 5 focuses on wastewater treatment and water reuse in the lower part.


Picture: F. M. Riese

4. Upper Lurín Catchment: Rural Highland Community

San Andrés de Tupicocha

Organizing authors: Michael Hügler & Stephan Wasielewski


Picture: M. Krauss

4.1 General Overview

The highland community San Andrés de Tupicocha (3 500 m asl, Figure 4.1) served as a case study in the TRUST project. We selected the community to record exemplarily the drinking water supply and wastewater disposal situation for a typical community of the Peruvian Andes and in the upper Lurín catchment area. The aim was to develop integrated sustainable drinking water supply and wastewater disposal concepts for such communities.

» ***Figure 4.1:*** *The center village of San Andrés de Tupicocha showing the typical land use in the upper catchment area in the dry season with irrigated and non-irrigated, partly terraced fields, surrounded by eucalyptus groves and pastures. Picture: M. Krauss.*

The district San Andrés de Tupicocha consists of the village and eight surrounding settlements, the so-called anexos. These anexos are affiliated communities, which extend from hermitages to smaller settlements. About 780 inhabitants live in the center village, and 654 in the anexos, the community thus has around 1 400 inhabitants (INEI, 2018). As typical for smaller settlements in Peru, drinking water supply and wastewater disposal are organized in a decentralized way and are operated by a communal water organization (JASS). JASS carries out the work on a voluntary basis and is mainly responsible for the management and maintenance of the facilities.

In the center village of Tupicocha, the majority of households have their own domestic drinking water connection as well as access to basic sanitation (e.g., public toilets). The sanitary facilities in the anexos are not as well developed as those of the center village since basic sanitation and/or sewage systems are missing or not completed and water treatment is insufficient.

An analysis of actor constellations was carried out and a mapping of the relevant water-related actors was prepared. This classification served to analyze the actors' positioning regarding the implementation of innovative water management concepts and to derive adequate participation strategies and dialogue formats with relevant stakeholders.

The limited data availability made it difficult to analyze drinking water quality without additional data collection. Through the evaluation of the available water (and wastewater) resources – based on the assessment of local data sets and reports supplemented with the monitoring mentioned above – concepts for improving the drinking water and wastewater situation were developed in cooperation with local actors.

These concepts have a direct impact on target 6.1 access to safe and affordable drinking water, target 6.2 access to adequate and equitable sanitation and hygiene, target 6.3 to improve the water quality and to increasing safe reuse of wastewater for agricultural purposes, target 6.4 to address water scarcity, as well as target 6.6 to protect and restore water-related ecosystems, including aquifers and lakes.

4.2 Water Governance Actors

Yvonne Zahumensky, Fabienne Minn, Christian D. León

4.2.1 Mapping of Water-Related Actors

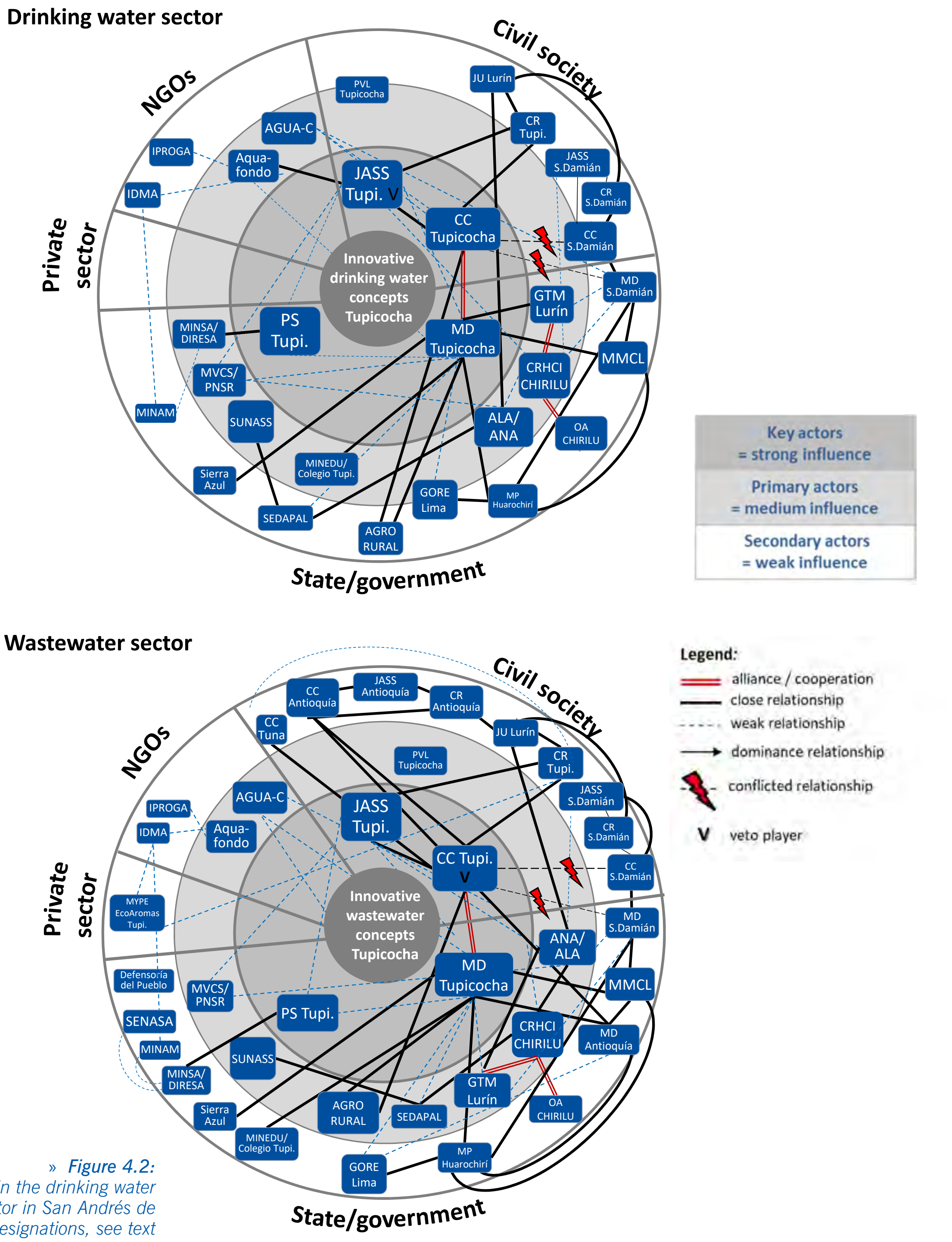
The social, political and cultural characteristics of the rural communities in the Peruvian highlands present specific framework conditions for implementing drinking water and wastewater projects.

To reveal socioeconomic boundary conditions for a typical rural community of the upper Lurín catchment, we carried out an analysis of actor constellations for the drinking water and the wastewater sector in Tupicocha. To this end, we realized a document analysis, conducted a focus group with local women and carried out interviews with key actors, e.g., current and former members of the JASS' directive board, municipal managers and local experts.

A mapping of the relevant water-related actors and their potential influences is shown in Figure 4.2 for the drinking water and for the wastewater sector.

The key actors regarding drinking water are the local peasant community (Comunidad Campesina, CC), the municipal administration (Municipalidad, MD), the local health post (Puesto de Salud, PS) and the communal water organization (Junta Administradora de Servicios de Saneamiento, JASS). The private sector is not present. The actors have heterogeneous degrees of influence. Compared to the civil society actors, there is only a slight predominance of state actors. Their influence consists in the fact that on the one hand civil society actors are networking with each other, and that on the other hand state actors are well connected among each other. The main link between the state and civil society sector is the alliance between the peasant community (CC) and the municipal administration (MD).

Within the wastewater sector, the key actors are the peasant community (CC), the municipal administration (MD), the local health post (PS) and the communal water organization (JASS). However, compared to the drinking water sector, there are considerably more actors involved. A strikingly large number of them are secondary actors with weak influence on local wastewater management. Nevertheless, these actors are not irrelevant, since their weight could increase in the future, if the topic of wastewater was to be ranked higher on the agenda of the local actors.



» *Figure 4.2:*
Mapping of actors in the drinking water and wastewater sector in San Andrés de Tupicocha (for full designations, see text and list of abbreviations).

The number of civil society and state actors is mostly balanced. The civil society actors are strongly connected, with the peasant community as an important node. The state actors are strongly networked with each other as well, and - similar to the drinking water sector - are connected to the municipal administration. State and civil society actors are linked by the alliance of the peasant community and the municipality. The private sector is hardly present and only weakly connected with the other sectors.

4.2.2 Description of the Key Actors

Comunidad Campesina (CC)

Comunidades campesinas (CC) are traditional (indigenous) rural peasant communities which organize themselves around local natural water sources, micro river basins and sub-catchment areas. They are defined as civil society organizations with public interest, i.e., representing the members' interests. Over time, specific semi-formal traditions of self-organization of the communities have been established in the region and some traditional management mechanisms perpetuate until today. The members of the CC are families who inhabit and control certain territories, and are linked by ancestral, social, economic and cultural ties. The community spirit is based on a common system of values and consensus among the members. All members have the right to benefit from goods or services of the community, but they are also obliged to get involved in community work (faenas).

Since the peasant communities usually are owners of partially extensive land properties, they play a vital role as a local partner and counterpart to the municipality and can even act as veto players in decision-making processes.

With a member base of about 300 farmers owning around 12 000 hectares of land, the CC of Tupicocha represents an important collaborator for the municipality and its mayor. The main objective of the CC is to promote agricultural production, as well as to represent the farmers' interests with regard to the use of the scarce (water) resources. Together with the municipality and the local irrigation committee, the CC's main tasks in Tupicocha regarding water issues focus on the construction of dams, reservoirs and irrigation channels. Compared to other peasant communities, the CC of Tupicocha has developed advanced experience and knowledge about water management.

Municipalidad Distrital de San Andrés de Tupicocha (MD)

The district of San Andrés de Tupicocha is located in the province of Huarochirí, department of Lima. The District Municipality (MD) is responsible for the administration of the district, which includes the center village Tupicocha and its anexos. Concerning water and sanitation issues, current and former district administrations have shown a constant interest and have been active in this area in a number of ways. Beyond the boundaries of the district, the District Municipality of Tupicocha is also linked to other state and civil society actors of the water sector in the Lurín catchment. For instance, the municipality of Tupicocha participates in the Multisectoral Working Group for the Lurín River Catchment (Grupo de Trabajo Multisectorial de la Cuenca del Río Lurín, GTM) and is part of the inter-municipal Association of Municipalities in the Lurín Valley (Mancomunidad Municipal de la Cuenca del Valle Lurín, MMCL).

Until recently, a particular focus of the activities of the municipality in the water sector has been on storing rainwater for irrigation purposes and as drinking water, by the construction of new water reservoirs and the expansion of existing ones. To accomplish the construction and maintenance of the water infrastructure, the municipality as local state actor, works closely together with the local CC. The collaboration between these two actors represents an important exchange between state and civil society as well as an important link between formal and informal governance structures.

Due to processes of decentralizing government in Peru since the 1990s, the responsibility for drinking water and sanitation services has been transferred to local levels of government, too. Local governments assume - directly or by concession - the administration and regulation of the water and sanitation services. In rural communities or small cities, the services can be provided either by the municipality itself, by specialized operators or by communal organizations. The district municipality is responsible to register the service providers to ensure the sustainability of the systems and to participate in the financing of the service providers according to the municipal budget (MVCS, 2017).

Área Técnica Municipal para la Gestión de los Servicios de Agua y Saneamiento (ATM)

Since the water and sanitation services are provided by communal organizations – like it is the case in Tupicocha – the district municipalities need to provide within their organizational structure a so-called Municipal Technical Division for Water and Sanitation (Área Técnica Municipal para la gestión de los servicios de agua y saneamiento, ATM). In general, the ATM is responsible for supervising, monitoring and providing technical assistance to water and sanitation services in small villages and rural areas (MVCS, 2017).

In Tupicocha, the ATM appeared to have been rather inactive in the past and is now concentrating its efforts mainly on supporting the JASS in the surrounding anexos to counter their precarious drinking water and wastewater situation. A closer collaboration with the JASS of the center village would be beneficial, since members of the JASS have expressed their wish to obtain more technical and general municipal support in their work. Encouraging is that the person in charge at the ATM Tupicocha is familiar with different consultation options on the regional level and is actively using those connections. It seems that - similar to many other ATM in Peru - the ATM of Tupicocha is hindered in functioning effectively due to insufficient financial resources, staff shortages and personnel turnovers.

Puesto de Salud (PS)

Local health posts (Puesto de Salud, PS) are local representatives of the health sector and perform essential health care services in rural areas. They depend on the Ministry of Health at the national level and on the Regional Health Directorate (Dirección Regional de Salud, DIRESA) at the regional level. With regard to the water sector, the health posts assume important tasks in controlling and monitoring drinking water quality. The results of the monitoring are fed back to municipalities and JASS. However, the local health post in Tupicocha (as many others in the region) does not possess the necessary personnel and resources to guarantee a continuous monitoring of the water quality. Furthermore, it seems that in Tupicocha the cooperation between the local health post and the JASS as well as the ATM needs to be strengthened.

Junta Administradora de Servicios de Saneamiento (JASS)

Particularly important organizations in the water sector of Tupicocha are the communal water organizations JASS (Juntas Administradoras de Servicios de Saneamiento), as they are responsible for water and sanitation services in the village and many of the anexos. The JASS of the center village of Tupicocha has been set up in 2007, when the public water dispensers (pilones) were replaced by a central water distribution and sewage system providing domestic connections. In addition to the elected voluntary members of the directive board, an operator is employed part-time by the JASS to operate the infrastructure, receiving a small monetary compensation.

As almost all community-managed water organizations, the JASS Tupicocha generally lacks personnel resources. Since the members contribute their workforce on a voluntary basis, their constraints in financial and time resources makes it difficult to fulfil all their tasks. This is also reflected in some shortcomings in their democratic functioning, e.g., the frequency of assembly meetings is lower than prescribed, and there are difficulties to meet the required gender quota for the directive board. It is also possible that infractions of rules or payment defaults go unsanctioned since the members of the JASS' directive board do not have the capacities to follow up on all matters.

In general, the members of the JASS' directive board wish for a higher priority of water issues in the municipality and the community. They also request more financial and communal support as well as more appreciation of their efforts. In this respect, the municipal ATM, which aims at the technical support of communal water organizations, could play an important role and contribute to further capacitate and support the personnel of the JASS. This seems to be challenging, since the ATM in Tupicocha also lacks financial and personnel resources.

In sum, important key actors of the water sector in Tupicocha like JASS and ATM are constrained by insufficient technical, financial and personnel resources. The lack of funding and a high staff turnover also impedes the development of these organizations as well as their capacities to implement long-term, future-oriented and sustainable strategies for their organizations as well as for sustainable water management in general.

These and further constraints of local conditions play an important role in the search for sustainable concepts for drinking water supply and wastewater disposal and are therefore taken into account in developing technical concepts.

4.3 Water Supply Situation

4.3.1 Drinking Water Supply

Stefan Stauder, Michael Hügler, Manuel Krauss

In and near the village of San Andrés de Tupicocha, two reservoirs (Figure 4.3) and four springs (Figure 4.5, Figure 4.6) provide drinking water. Spring water is mainly used for agricultural purposes, but also as drinking water (mainly directly collected at the springs in small containers), in addition to the pipe-based water supply out of the reservoirs. The latter was set up in 2007 to improve the supply situation for the estimated 780 inhabitants of the center village. Therefore, the majority of households of the village is connected to the drinking water system.

Most households are continuously supplied with water, although water rationing may occur in dry seasons (between June and September), allowing only a partial supply of the village and engaging protocols of water rationing. During water rationing or when the system has to be switched off (e.g., in case of damage to infrastructures), residents also resort to natural water sources (springs) for their supply.

As mentioned before, the local JASS is responsible for the operation of this water supply, the facilities (e.g., pipelines, storage tank) and also raises the water tariff. A JASS employee regularly checks the water transport lines for damages and cleans the pressure relief shafts.

Raw Water Resources

As mentioned above the drinking water for the center village of Tupicocha is mainly supplied from two reservoirs, the Ururí reservoir (3 800 m asl, approx. 5 km east from Tupicocha, Figure 4.3) and Tuctococha reservoir (4 400 m asl, approx. 25 km away). The latter flows to the Ururí dam via a covered, approximately 23 km long canal. The waters from both reservoirs are mixed in a small mixing chamber before they are further transported to Tupicocha.

In dry years, such as 2018, the Ururí reservoir (Figure 4.3) can dry out, resulting in restrictions in the local drinking water supply.

» ***Figure 4.3:*** *Ururí reservoir at the end of the rainy season (above, March 2019), and at the end of the dry season (below, November 2018). Pictures: M. Krauss.*

The Ururí reservoir water is not used directly, instead the water leaching through the dam is collected at its foot (see Figure 4.8). Most of the area for leachate collection is fenced in order to protect the area from grazing cattle. However, the fence has been damaged to allow sheep to graze on this rather green land (see Figure 4.8).

The leachate from Ururí flows in a PVC pipe into the collecting chamber where it is mixed with water from the Tuctococha dam. The contingent of the two resources varies seasonally, according to the filling level of the reservoirs. From the collecting chamber, the water flows to the water tank of Tupicocha (Figure 4.4) via an approximately 6 km long pipeline. The exact pipe run, partly underground and partly above ground, is not mapped. Several intermediate shafts in the pipeline relieve the pressure. This is necessary due to the large height differences between the Ururí dam and the water tank (approx. 400 m, corresponding to 40 bar).

Water treatment, storage and distribution

The facilities for water supply are situated 50-150 m above the center village of Tupicocha (Figure 4.4). The drinking water tank, has a storage volume of approx. 60 m^3 and has to be cleaned several times a year due to accumulation of organic solids.

» ***Figure 4.4:*** *Water storage tank of Tupicocha with a shed for chlorine dosage on top. Picture: M. Krauss.*

The water from the tank is fed by gravity into the distribution network of Tupicocha. Drinking water is currently distributed without further treatment or sufficient disinfection and shows fecal microbiological contamination (see below).

The small brick construction (Figure 4.4) on top of the water tank houses a drip chlorination device, consisting of a barrel for a calcium hypochlorite solution that is fed into the drinking water tank via a hose line with a manual valve. Yet, chlorination was not in operation during several site visits between 2017 and 2019. According to the local JASS, the consumption of chlorine (if executed) is approx. 1 gallon (3.8 L) per month, which would correspond, according to our calculations, to a final chlorine concentration of approx. 0.1 mg/L. With regard to the actual water quality (see below), this chlorine concentration is rather low and very likely not sufficient to guarantee a safe disinfection.

Thus, it has to be emphasized, that an adequate/ safe disinfection cannot be guaranteed for several reasons:

- Chlorine dosage amount is too low
- No continuous chlorination
- No particle removal (turbid water especially during the rainy season)
- High probability, that chlorine resistant pathogens are present in the water

The inhabitants of Tupicocha seem to be aware of these circumstances: Interviews revealed that tap water is boiled in many households before drinking, (using firewood for boiling).

No reliable data/information on the supply network is available for Tupicocha. There is no division of the distribution system into different pressure zones. With larger withdrawals in the lower part of the network, there are significant pressure drops in the upper part.

Water Tariffs and Water Demand

The households of Tupicocha who are connected to the supply system pay a monthly tariff (cuota familiar) of 3 PEN (approx. 1 USD, 0.8 EUR) for the use of the water and sanitation services. To put this tariff into relation: The median monthly income of Tupicochas´ residents in 2012 was € 55, which is in the range of the Peruvian and the international poverty line of € 60 (JBIC, 2007; Worldbank). Therefore, in Tupicocha the average percentage of the income payed for water and sanitation of 1.5 % is already close to the corresponding value in Germany (approximately 2.0 %). The revenues generated by the monthly tariff are used by the JASS for operation and maintenance of the system. As reported by the JASS directive board, the willingness to pay the monthly tariff poses problems, as many households pay their fees too late or not at all. On the one hand, this can lead to short-term restrictions in the operation, e.g., when the operator cannot be payed or the chlorine cannot be bought. On the other hand, it means that in the long term no major investments can be made and planning capabilities are impeded.

The water tariff is not based on the actual water consumption, but is a fixed charge. Households in Tupicocha do not have any counting devices, like, e.g., water meters. Consequently, there is no monetary incentive to use the scarce resource drinking water sparingly. In order to achieve better control of water use, previous and current members of the JASS directive board recommend the introduction of water meters to determine tariffs according to the individual consumption of the households. This not only aims at saving water in the households, but less water consumption would also allow a longer reaction time for chlorine in the central water tank, therefore providing better disinfection. However, the JASS currently lacks the financial means to install water meters and suspects that the population would reject this initiative as they fear an increase of their monthly tariffs.

According to the World Health Organization, a continuous supply with an average quantity of 100 liter per capita and day (L/c/d) reflect the "desired service level", and "optimal access" to drinking water respectively (Howard & Bartram, 2003). The Peruvian ministry designates a value of 80 L/c/d (MVCS, 2018). For the approximately 780 inhabitants of the center village of Tupicocha this corresponds to a total daily demand of 60 to 78 m^3. However, real water losses in the distribution system and deficits in costumer awareness regarding minimization of water consumption ("apparent losses") have to be considered. The latter might be a consequence of absent water metering. From our analyses, an actual water consumption of up to 300 L/c/d was estimated.

Our considerations on how to optimize the drinking water supply in Tupicocha (Chapter 4.5) were based on a peak demand of 150 m^3 per day (200 L/c/d). With respect to the limited raw water resources, the real and apparent water losses must be minimized in case that this peak demand will be not sufficient.

4.3.2 Local Perception of Water Services

Fabienne Minn & Hannah Kosow

The following description of the perceived state of the water supply system and the quality of water services in Tupicocha are based on multiple empirical sources: several qualitative interviews with local stakeholders and experts were conducted between 2017 and 2019 and a transect walk with pupils of the local school César Vallejo took place in March 2018. In 2019, a focus group with women to assess the general attitudes towards the quality of water services took place in March, as well as a participatory assessment workshop with key stakeholders in November (see section 4.5.3). In March 2020, we also conducted several semi-structured interviews with current and former members of the JASS' directive board, representatives of the municipality as well as other local experts. These structured and semi-structured forms of data collection were completed by many informal talks and other sources of information during the course of the project.

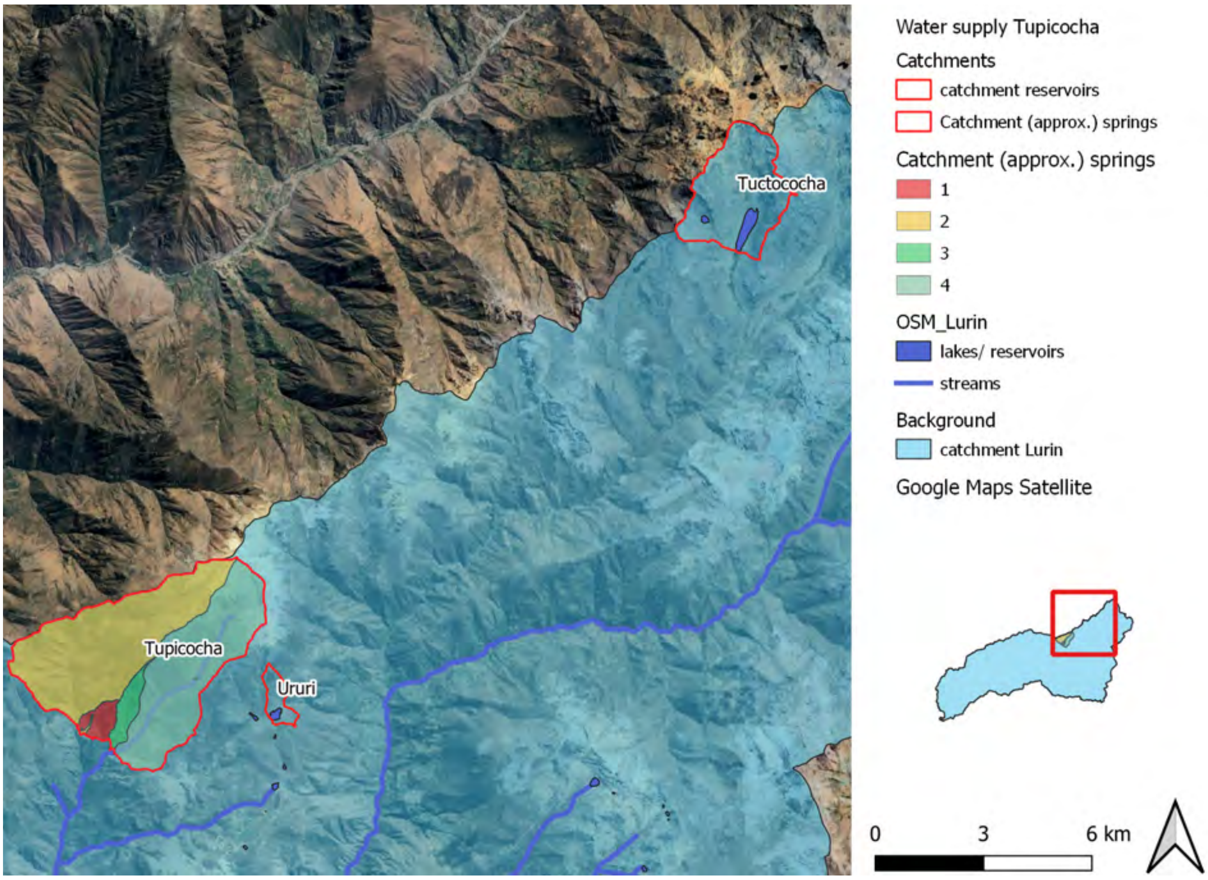
In general, the connections to the drinking water and sewage systems are regarded by the population of Tupicocha as a positive achievement, improving the quality of life and making daily tasks easier, particularly for many women. However, the quality of the drinking water is often criticized. All interlocutors complained that during the rainy season sediments often cause turbidity in the water. When there are sediments in the water, the water is left to stand so that the sediments can settle. In addition, the vast majority of the interviewees stated that they did not drink their water directly from the tap but that they boiled it before consuming it, a practice which they did not report as bothersome. It was stated that on one occasion many children got sick. This incident was related to dead animals in the canal close to the Ururí reservoir, causing a deficient water quality. Despite these findings, a large proportion of the interviewees (women and pupils) stated that the lack of water quality did not lead to (diarrheal) diseases, while some individuals strongly attribute their illness to the poor water quality.

Both current and former members of the JASS' directive board are aware of the poor water quality and regard it as a risk to the population and a threat to public health. Continuous chlorination could help to some extend to improve the water quality; however, this presents some difficulties for the JASS, e.g., technical difficulties in administering the adequate dosage of chlorine, or procuring the chlorine. Additionally, members of the JASS' directive board state that problems of dosing the chlorine led to complaints of the population regarding the taste of the water. Oppositely, other parts of the consulted population reported however, that they did not mind the taste of chlorine in the water.

Overall, it seems that the assessment of the current drinking water situation is partly based on a shared perception of the problem (e.g., concerning turbidity, water shortages), but also varies to some extent among the respondents (e.g., concerning the effects of the poor water quality on public health). Solutions proposed by local actors to resolve the current problems of water quality and quantity include better water protection, monitoring of water quality and water consumption, building new water tanks, and tapping new water sources.

4.3.3 Hazard Analysis and Protective Effect of the Catchment Areas
Thilo Fischer, Friederike Brauer, Sebastian Sturm

As already mentioned, the water supply system of the center village of Tupicocha gets its raw water from two reservoirs which are situated several kilometres from the village. In addition, springs in or close to the village are used for private supply ("pick up" via bottles and containers). The catchments of the reservoirs and the approximated catchment of the springs are shown in Figure 4.5. We evaluated both with regard to hazards and the protective effects of the catchments.

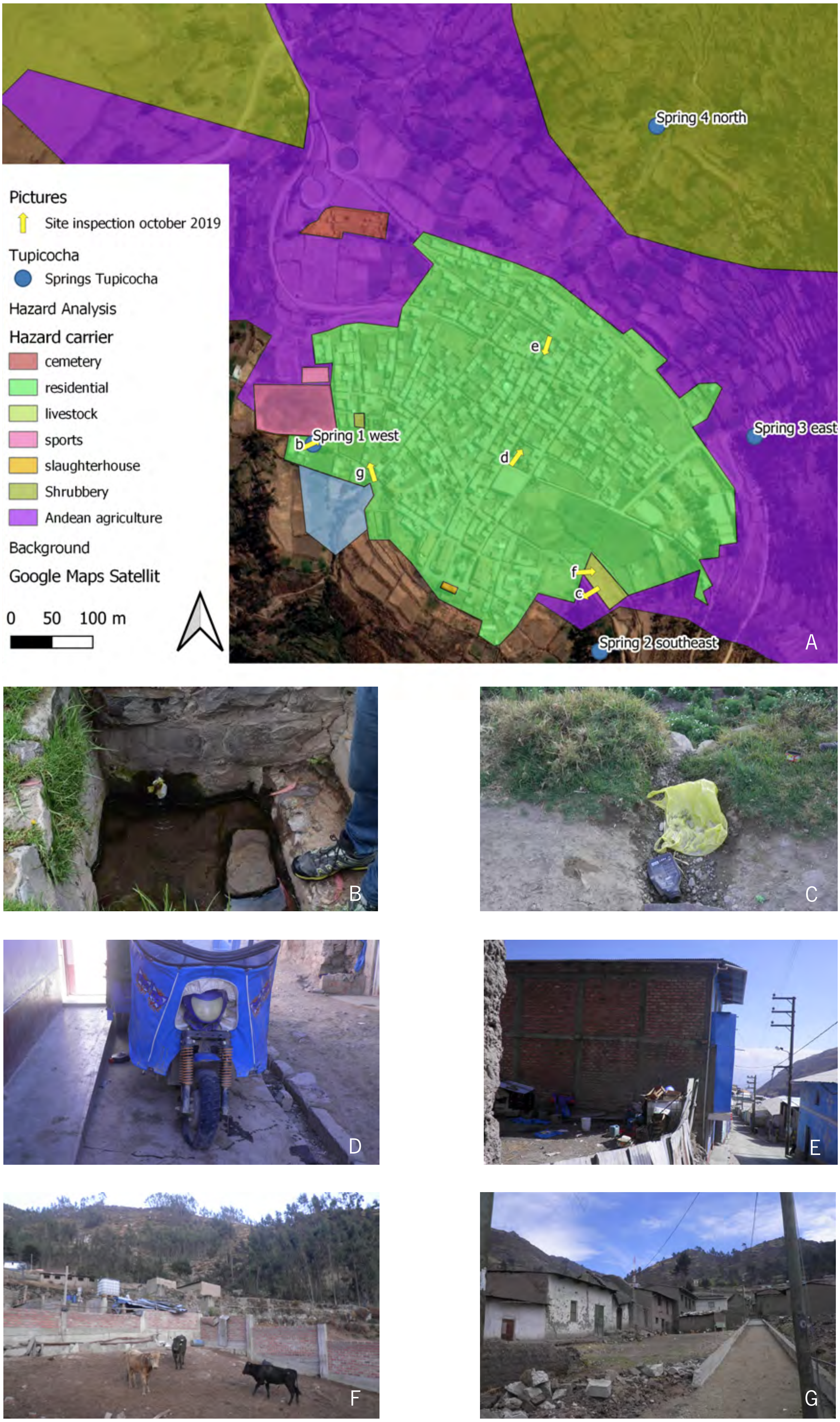


» *Figure 4.5: Catchment of the springs and the reservoirs used by the center village of Tupicocha.*

Hazard Analysis for the Spring Waters

A land use map provided by the National Environmental Information System (Sistema Nacional de Información Ambiental (SINIA)) of the Peruvian Ministry for Environment (Ministerio del Ambiente) was used to identify hazard carriers in the catchment of the springs. Additionally, a site inspection of the village of Tupicocha in October 2019 enabled a detailed hazard analysis (see pictures and map in Figure 4.6).

Spring 1 (Chiribamba) is the most important spring in Tupicocha to collect drinking water. There are no fences or other measures to prevent animals from penetrating the area, thus animal feces were present in the vicinity of the spring. Furthermore, a lot of plastic waste could be found close to the spring, as well as at several locations in the village, including empty oil bottles. Some spilled oil was also visible (Figure 4.6). In the village a backyard with a cubic meter tank filled with an unknown liquid was found. Another aspect is the livestock that is kept by many villagers in the village (e.g., cattle or chicken only a few meters away from the springs (Figure 4.6)).

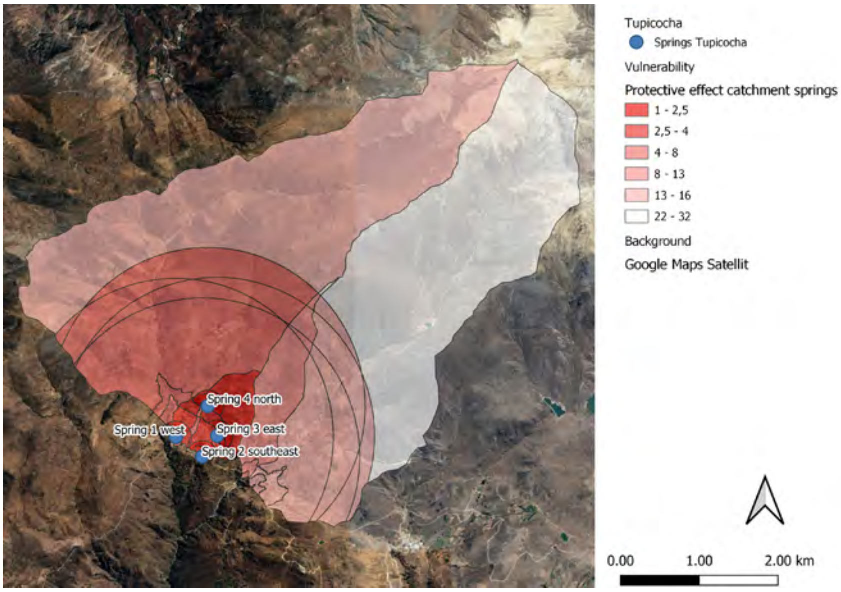


» *Figure 4.6:*
Hazard analysis of the springs in Tupicocha, October 2019.
(A) Map showing the springs, the land use and the places of the pictures, (B) Spring 1 Chiribamba, (C) waste near spring 1, (D) spilled oil, (E) tank with unknown liquid, (F, G) livestock (Pictures: M. Krauss (B) T. Fischer (C-G)).

Protective Effect of Spring Water Catchment Areas

Due to the fact that the catchment area of the four springs is not known and detailed hydrological profiles of the area were not available, the four closest surface water catchments were used as an approximation to estimate the catchments (Figure 4.7). The geological layer Rímac formation is part of each of those catchment areas. Thus, a connection to the groundwater body of the springs is theoretically possible. The elevation does not prevent a connection either.

The further calculations are based on the following assumption: The closer a surface water body comes to the village, the higher the likelihood that the groundwater body of the springs is influenced by its catchment area (1=high influence; 4=low influence). Another factor of influence is the absolute distance to the springs ranging from 1 (less than 20 m) to 8 (more than 2 km). The protective effect assigned to the catchment area and the distances to the springs are combined. The two mentioned factors are multiplied to estimate the total protective effect of the area. The higher the resulting number, the higher the respective protective effect. The result is shown in the following map (Figure 4.7).

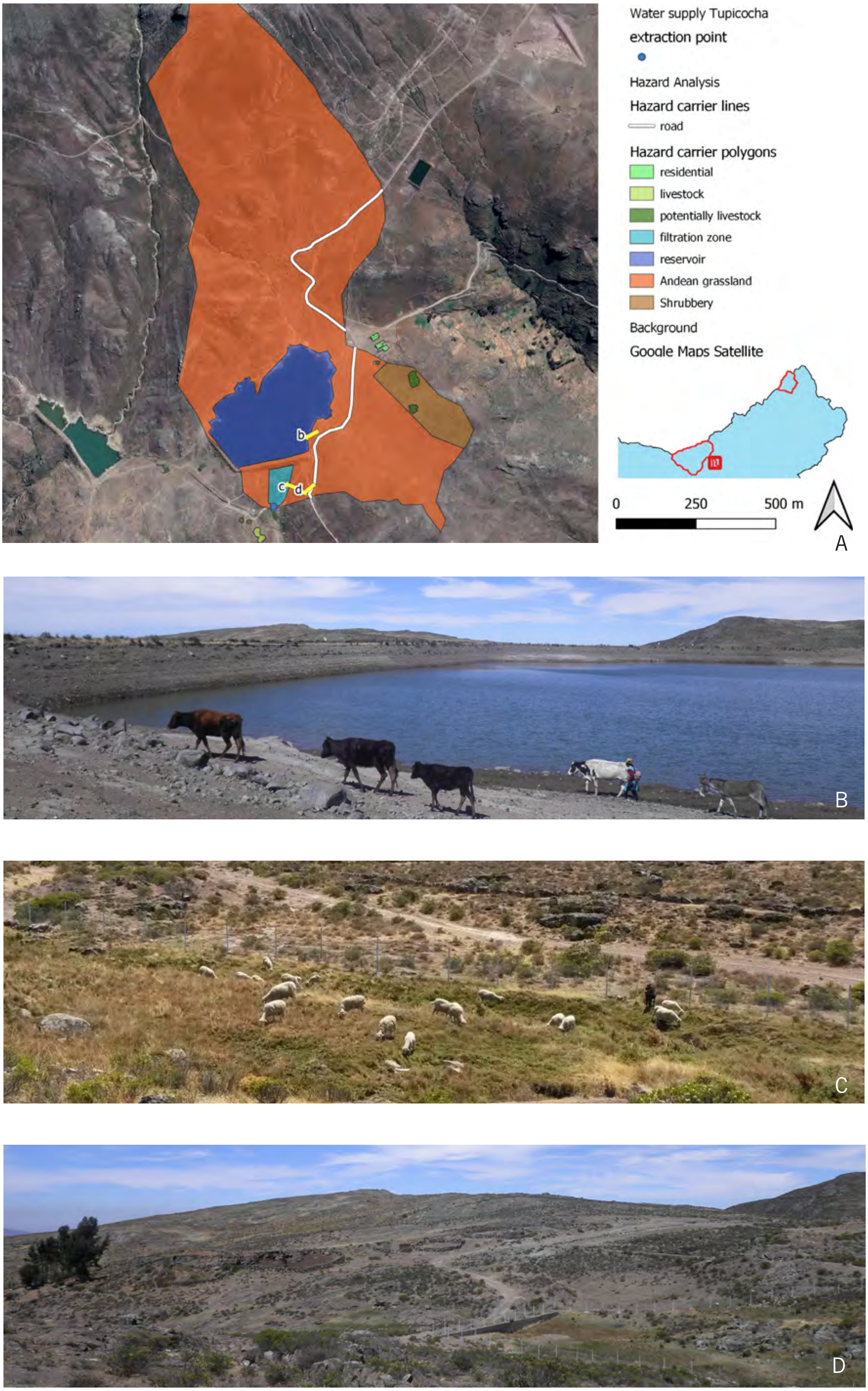


» *Figure 4.7: Total protective effect of the springs´ catchment areas in Tupicocha.*

Hazard Analysis Ururí Reservoir

The Ururí reservoir was inspected on site to enable a detailed hazard analysis. Additionally, the land use map provided by the National Environmental Information System (SINIA) of the Peruvian Ministry for Environment was used for the identification of hazard carriers in the catchment of the reservoir. The hazard carriers identified are shown in Figure 4.8.

The reservoir lake is accessible without any restrictions and the reservoir is used to water cattle. As a result, feces were found all along the shoreline. As mentioned above, the raw water is not abstracted directly from the lake. Instead, the reservoir dam and the area below serve as a filter before the water is channelled to the pipeline at the extraction point. The filtration zone below the dam is protected by a fence (Figure 4.8). However, the fence was damaged to allow sheep to graze on this rather green land and livestock was observed in the fenced area during several site inspections. The main part of the catchment area consists of Andean grassland which is used for extensive grazing (Figure 4.8).



» ***Figure 4.8:*** *Hazard analysis of the Ururí reservoir, October 2019. (A) Map showing the land use and the locations of the pictures (B) livestock at the reservoir, (C) grazing sheep within the fenced area below the dam, (D) Andean grassland (Pictures: T. Fischer (B, D), M. Hügler (C)).*

Protective Effect of the Ururí Catchment Area

Two factors were used to calculate the protective effect of the area of the surface water catchment of the Ururí reservoir: The distance to the surface water and the slope of the area. Both influence the time hazards need to get from the hazard carrier to the reservoir and to the extraction point.

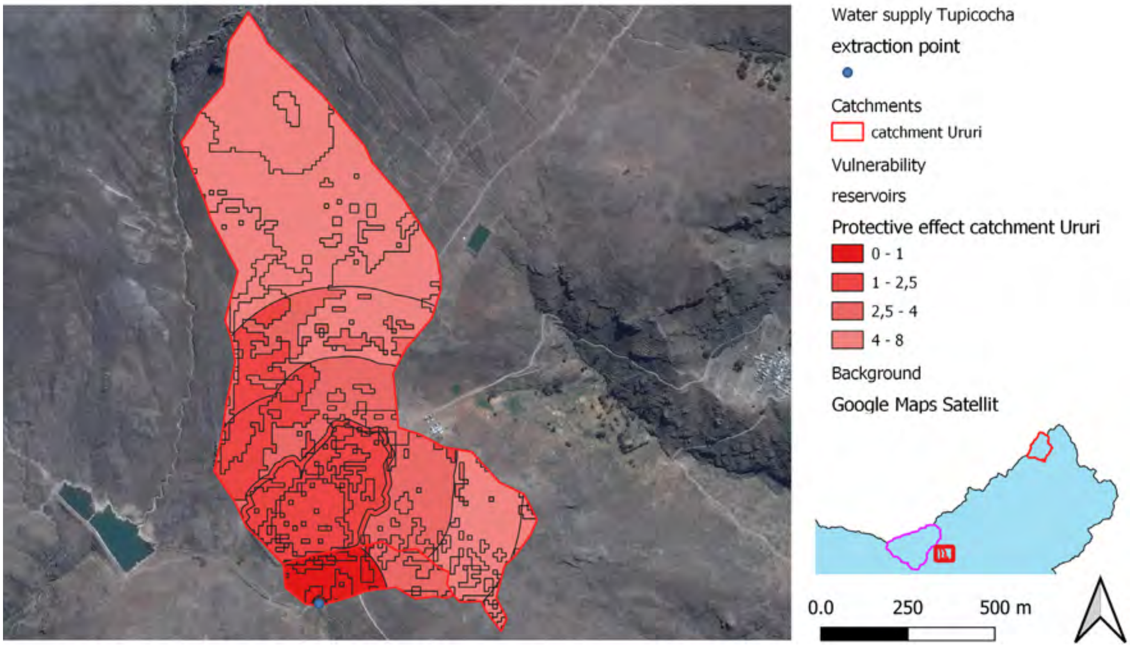
The protective effect of the catchment area (altitude: approximately 3 850 to 4 200 m asl) also depends on the amount of rain during a rainfall event. The climate stations that were installed by TRUST during the project are not located exactly within the catchment of the reservoir. But the measurements at the nearest climate stations indicate that the amount of rain on most days in the surroundings of the reservoirs did not exceed 20 mm/d. However, the measurements showed that short single rain events can reach intensities over 20 mm/h.

Another important parameter is the infiltration capacity of the soil as it influences the formation of overland flow (Horton, 1933). Unfortunately, this information was not available for the catchment of the Ururí reservoir. During the project, measurements of the soil texture were conducted in the area. The closest one was on a slope of shrubbery around 2 km from the Ururí reservoir; around 200 m lower in altitude and in the same geologic formation (Huarochirí) as the upper part of the catchment. It is a clay loam that should be able to infiltrate 130 mm/d (Ad-hoc-AG Boden, 2005) or around 5 mm/h. Another site for soil texture measurements was close to a lake in Andean grassland, approximately 9 km from the reservoir and around 600 m higher in altitude. It is sandy clay with a coefficient of hydraulic permeability of 380 mm/d (Ad-hoc-AG Boden, 2005) or around 15 mm/h. In both cases a short and heavy rain event with an intensity of 20 mm/h could trigger overland flow.

The values chosen to consider the influence of the distance to the reservoirs are between 0 and 4. The factor rises from 0.2 to 1 at a distance of 200 m from the surface water. This is due to the assumption that 200 m is the maximum distance that fast flow components like overland flow and interflow can reach (Peschke, 1998). The slope influences the likelihood for water infiltrations. Therefore, the slope was categorized, showing a strong increase of this factor at 10 degrees. This is based on the higher likelihood for the occurrence of overland flow above this threshold (Peschke, 1998).

The protective effect of the filtration through the dam and the rest of the underground passage to the extraction point are taken into account by adding the value 2 to the product of these two factors. That equals to the factor for the protective effect of the distance to the springs between 20 m and 200 m. And that's because the distance from the reservoir to the extraction point is also between 20 m and 200 m and the water moves with a subsurface flow. This factor applies only to the area on the reservoir side of the dam.

The total protective effect of the catchment area is shown in Figure 4.9. The area between the dam and the extraction point around 100 m south of the dam is very important for the water quality as well, because hazards can reach the extraction point very quickly.



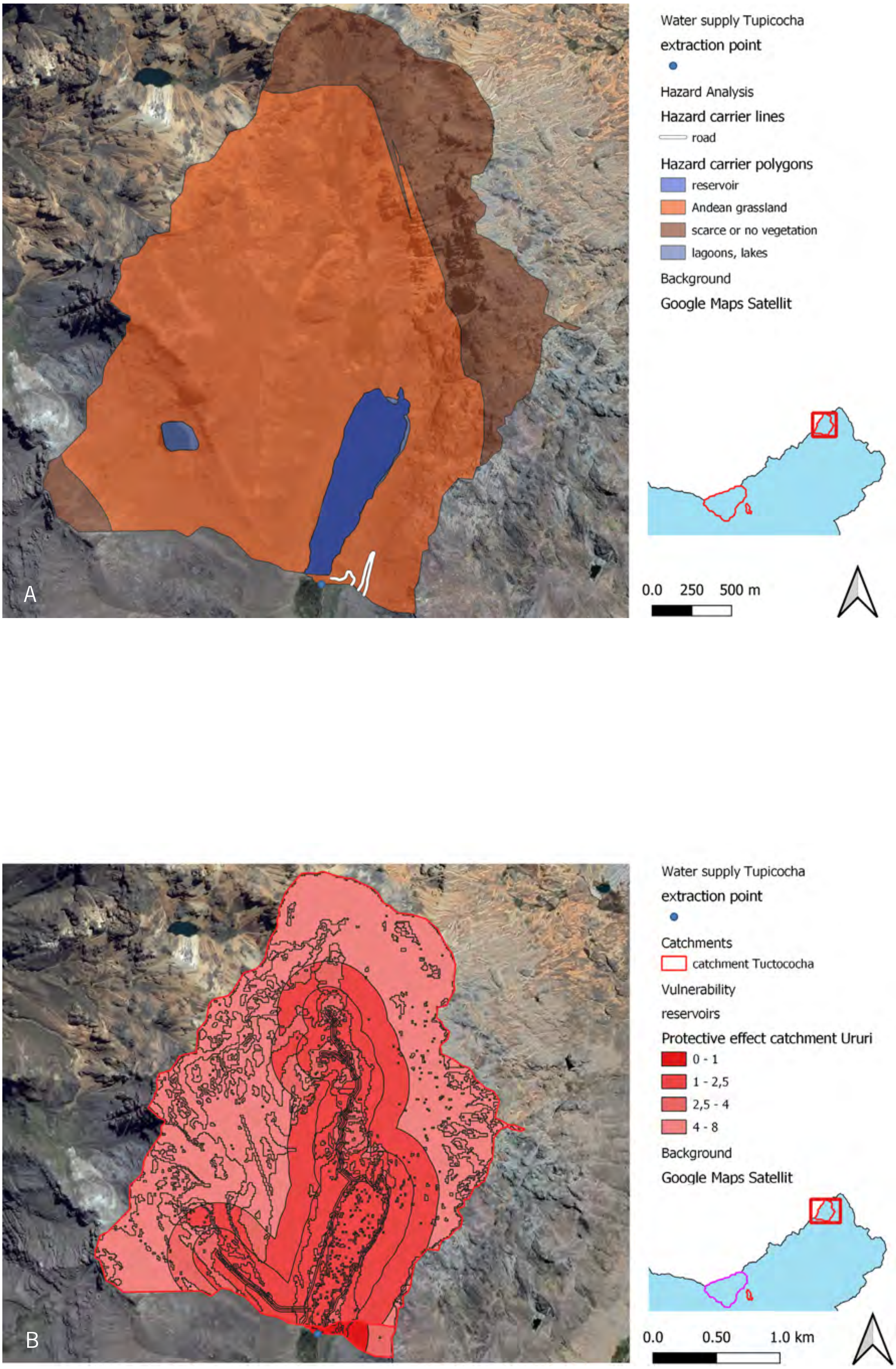
» *Figure 4.9: Total protective effect of the area of the Ururí reservoir.*

Hazard Analyses and Protective Effect of the Catchment Area of the Tuctococha Reservoir

There was no site inspection in this catchment (altitude: approximately 4 500 to 5 100 m asl) within the TRUST project because it is very difficult to access. The land use map provided by the National Environmental Information System (SINIA) of the the Peruvian Ministry for Environment was used to identify hazard carriers (Figure 4.10).

It was assumed that the extraction point is positioned around 100 m below the dam, analog to the abstraction at Ururí. The protective effect of the catchment area (Figure 4.10) was estimated analogously to the Ururí reservoir with the method described above. Due to small rivers which flow into the reservoir, the protective effect for some areas is very low although they are not close to the reservoir.

The area below the dam is the least protected within the area. Due to the fact that the exact position of the extraction point is unknown, the extent of this area could only be estimated.

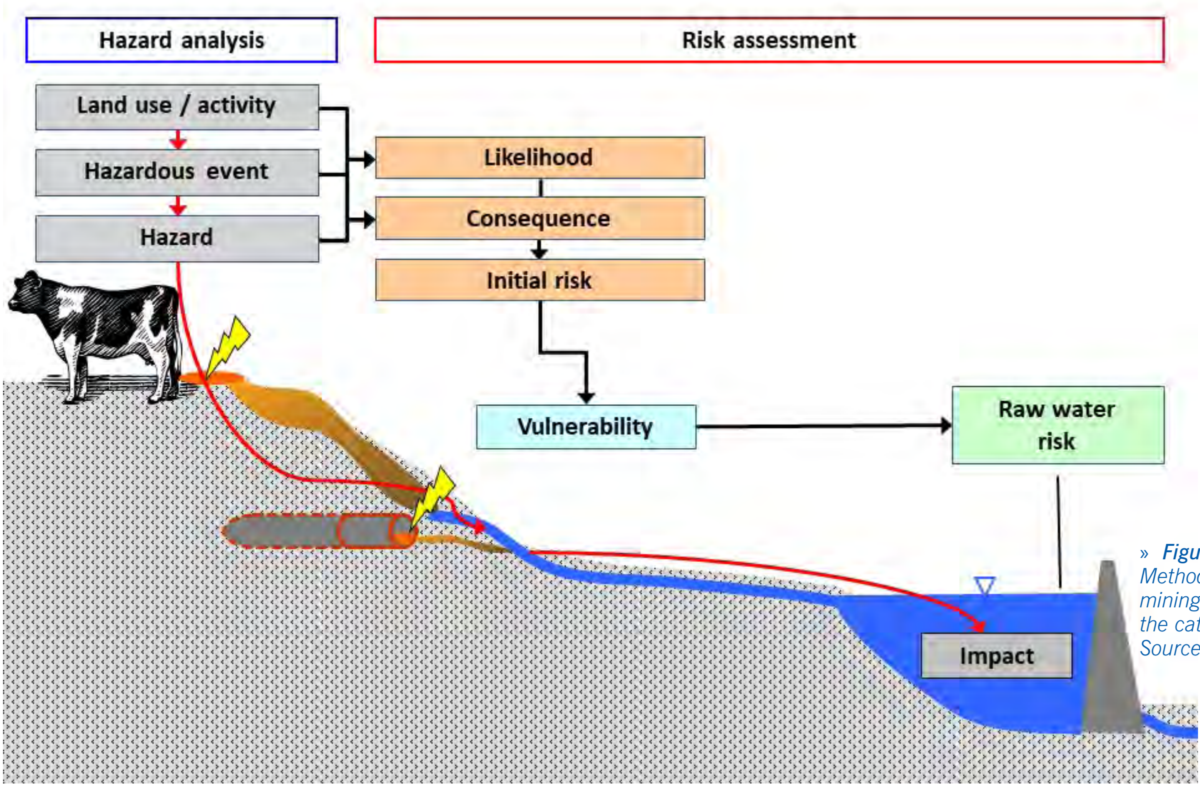


» ***Figure 4.10:*** *Hazard analysis (A), and total protective effect of the area (B) of the Tutococha reservoir.*

4.3.4 Risk Assessment

Friederike Brauer, Thilo Fischer, Sebastian Sturm

The risk assessment serves to prioritize existing risks. In the catchment area of the drinking water for Tupicocha, this supports to identify areas and actions, which pose particularly high risks for water supply. The risk assessment can facilitate the decision processes, on where risk control measures are primarily necessary to ensure the safety of the supply.



» *Figure 4.11: Method for determining the risk from the catchment area. Source: TZW.*

Figure 4.11 schematically shows the methodical approach to risk assessment in the catchment area. It is based on the results of the hazard analysis described in chapter 4.3.3. The risk for the raw water is derived from:

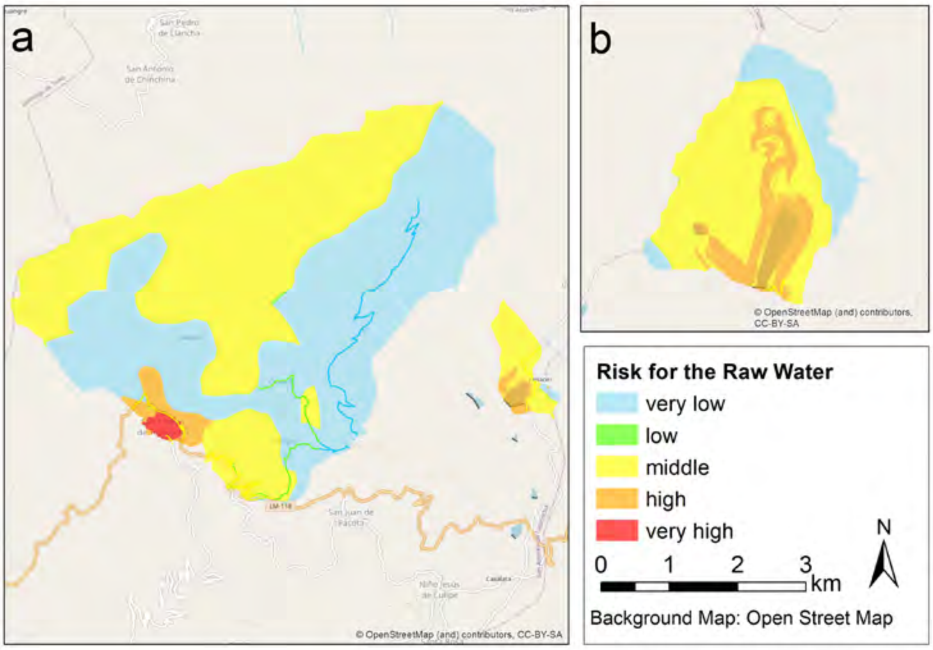
- The initial risk deduced from the severity of consequences and the probability of occurrence for hazardous events in the catchment area.
- The reduction of the initial risk through the protective function of the catchment area (chapter 4.3.3).

Likelihood of occurrence and severity of consequences are rated on a 5-step-scale. In order to weight the extent of the damage more strongly, a square row was chosen, while the likelihood of occurrence is scaled linearly. This ensures that hazardous events with a very high severity of consequences cannot be assigned a low initial risk. Risk fact sheets concerning the possible hazard carriers document the basis of the risk estimation. Exemplarily, Table 4.1 shows the risk fact sheet for settlements. All other uses and actions are evaluated accordingly.

» *Table 4.1: Risk fact sheet for the settlement area San Andrés de Tupicocha.*

SETTLEMENT	
Hazard analysis	
System component	Catchment
Sector	Settlement
Hazardous event	contaminated leachate
Hazard type	primarily microbiological, chemical
Specific land use objects	Residential buildings, access roads, livestock, slaughterhouse
Risk assessment	
Assessment of the initial risk	**Consequence: 25 (very high)** **Likelihood of occurrence: 5 (very high)** **Initial risk: 125 (very high)**
	Comments on the assessment of the consequences: Residential buildings (including small businesses) with sewage facilities (risk of unnoticed leaks, e.g., due to leaking house connections), potentially existing fuel tanks or similar, access roads and parking spaces for cars (drip losses and similar), handling of water-polluting substances (mostly small containers), livestock. Although the inventory of pollutants is limited in terms of quantity, there is a multitude of possible hazardous events and groups of pollutants (including microbiological hazards from wastewater or livestock). Since most of the streets in the village are not sealed, released substances are not retained. This is particularly true for hazards from underground sewage systems and house connections. **Comments on the assessment of the likelihood of occurrence:** A large number of partly punctual or small-scale discharges can be evaluated as „diffuse", i.e., there there is a regular pollutant input averaged over the area.

Ignoring the protective effect of the catchment area, most regions in the catchment area could pose a significant risk to the drinking water quality and are evaluated as a high or very high initial risk. A large part of the catchment area is not suitable for intensive agricultural use, but extensive pasture use is to be expected in most of the area. The microbiological hazards associated with livestock lead to a high initial risk. The settlement of Tupicocha itself causes the greatest initial risk. Generally, there are numerous potential hazardous events in settlement areas including potentially leaking sewage facilities and fuel tanks, access roads and parking spaces with the risk of drip losses and similar events. Additionally, there is livestock kept in the settlement causing microbiological hazards (Table 4.1). The combination of initial risk and protective function leads to an estimation of the risks for the quality of raw water. The areas displayed in orange or red in Figure 4.12 pose significant risks for the raw water. These are mainly the center village of Tupicocha and the pasture areas that are close to the springs in Tupicocha or to the reservoirs.



» *Figure 4.12:* *Maps showing the raw water risk (a: catchments of Tupicocha springs and Ururí reservoir, b: catchment of Tuctococha reservoir).*

The estimation concerning the reservoirs is confirmed by the analytical data (chapter 4.3.5). It shows that high numbers of coliform bacteria are frequently present in the water from Ururí and Tuctococha, as well as the detection of *E. coli* or other fecal indicators.

The calculations and evaluations can be performed with the help of any geographical information system (GIS). The WSP-Tool, developed within TRUST (chapter 2.6), facilitates the calculations as well as the documentation.
To ensure that water issues do not lead to health problems, control measures need to be taken. Ideally, the risk should be mitigated in the catchment area, for example by not allowing cattle and sheep to graze on vulnerable areas, particularly within the fenced area at the inner catchment, at Ururí. Further measures, including adequate treatment are discussed below (chapter 4.5).

4.3.5 Water Quality

Michael Hügler & Stefan Stauder

Between November 2017 and November 2019, we regularly analyzed several raw and drinking water samples of Tupicocha on microbiological and physico-chemical parameters. Table 4.2 lists selected data. The waters from the Ururí and Tuctococha reservoirs have a similar good physico-chemical quality. They are low in mineralization and accordingly rather soft (total Ca^{2+} and Mg^{2+} = 0.5 mmol/L). As expected, the turbidity of the water is seasonally high and sometimes exceeds the WHO drinking water standard of 5 NTU for small communities. With the exception of negligible traces of arsenic, no toxic trace elements or heavy metals are contained.

During passage of the water through the Ururí dam, no significant change in water quality occurs. Attention needs to be drawn to a seasonally increased content in humic substances (TOC value) and the presence of fecal indicator bacteria in the raw waters. Since no water treatment is applied, the quality of the drinking water in the village Tupicocha is the same as the raw water from the reservoirs. This is of special relevance with regard to the increased turbidity and the fecal contaminations.

» ***Table 4.2:** Selected analytical data from different raw and drinking waters in Tupicocha. Source: own measurements*

		URURÍ RESERVOIR	URURÍ DRAINAGE	TUCTOCOCHA RESERVOIR	DISTRIBUTION TUPICOCHA	SPRING CHIRIBAMBA
Sampling date		09.06.2018	09.06.2018	31.03.2019	31.03.2019	09.06.2018
Turbidity	NTU	-	-	11	12	-
Electr. Cond.	µS/cm	92	107	133	152	540
pH value	-	-	-	8	8.1	-
Alkalinity	mmol/L	0.5	0.9	-	-	3.1
Calcium	mg/L	10.5	9.9	14.2	14.9	70
Sodium	mg/L	3.4	3.5	3.9	3.9	18
Iron	mg/L	0.11	0.06	-	-	<0.1
Chloride	mg/L	<1.0	<1.0	<1.0	<1.0	11.7
TOC	mg/L	3.5	3.2	2.5	2.4	0.71
E. coli	n/100 mL	0	0	5	2	0
coliform bacteria	n/100 mL	313	933	980	1 017	410

The presence of indicator bacteria in the raw waters is probably a consequence from the usage of the two reservoirs to water cattle. The banks area is highly contaminated with animal excrements. These represent a source for fecal pollution of the lake water, including chlorine resistant pathogens (e. g., parasites oocysts).

In principle, the underground passage at Ururí dam provides an effective filtering effect, so that microorganisms in the lake water are believed to be retained. However, there is a high risk of secondary contamination due to grazing sheep in the drainage area and through garbage deposition (including baby diapers).

Another contamination pathway are the intermediate shafts (pressure breaking) in the pipeline to Tupicocha. The shafts only reach slightly above ground level and therefore soil material and animal excrements could be washed into the shafts in the rainy season. Some of the manhole covers have been designed as professional covers with locking and screwing, but some are only poorly covered and enable also an entry of small animals. Furthermore, the emergency overflows have no check valves.

To examine and evaluate the microbiological water quality, we took specific samples at various points of the distribution system of the center village of Tupicocha. Furthermore, two spring waters were sampled. The microbiological parameters were analyzed in the laboratory of TZW; exemplary data is shown in Table 4.3.

» *Table 4.3: Selected microbiological data from the distribution system and one spring water in San Andrés de Tupicocha. Source: own measurements.*

SAMPLING POINT	DATE	E. COLI MPN/100 mL	COLIFORM BACTERIA MPN/100 mL	ENTEROCOCCI CFU/100 mL	CLOSTRIDIUM PERFRINGENS CFU/100 mL	SOMATIC COLIPHAGES PFU/100 mL
distribution system sampling point 1	18.03.2018	6	345	0	0	1
	09.06.2018	1	123	2	1	2
	25.11.2018	2	1 017	0	0	2
	31.03.2019	1	144	4	0	6
	19.10.2019	2	270	12	1	2
distribution system sampling point 2	18.03.2018	5	276	2	0	3
	09.06.2018	0	231	5	2	0
	25.11.2018	2	98	3	4	0
	31.03.2019	3	222	5	1	2
	19.10.2019	0	206	1	2	0
spring water spring 1 Chiribamba	18.03.2018	0	62	0	0	0
	09.06.2018	0	410	0	0	0
	24.11.2018	0	387	30	0	0
	31.03.2019	2	166	0	0	0
	19.10.2019	0	1 120	0	0	0
spring water spring 2 southeast	18.03.2018	0	115	0	1	0
	31.03.2019	0	2	2	1	0
	19.10.2019	0	68	1	0	0

As shown in Table 4.3, the drinking water samples from the distribution system of Tupicocha generally showed microbiological contaminations. The fecal indicators *E. coli* and enterococci were detected in almost every sample. Also *Clostridium perfringens* as an indicator for parasites and somatic coliphages as a viral indicator were detectable. Based on these results, a contamination of the water supplied in Tupicocha with fecal bacterial, viral and parasitic pathogens is most likely.

In contrast, the water quality of the spring Chiribamba, which is also used by the people of Tupicocha as drinking water source, shows less frequent microbial contaminations. *E. coli* was only detected once, during the rainy season (March 2019), whereas *Clostridium perfringens* and somatic coliphages were not detected. Enterococci were detected once, yet these were identified as *Enterococcus termitis*, a species that is associated with insects and thus not related to fecal contaminations. Similarly, spring 2 shows fecal contaminations during the rainy season (detection of *Clostridium perfringens* in March 2018 and March 2019).

In summary, the distributed drinking water in Tupicocha is contaminated with waterborne pathogens and should not be used for drinking without further treatment and disinfection (like, e.g., boiling). The Chiribamba spring showed a better microbiological water quality at our control samples. However, there is a high risk for intermittent fecal contamination of the local springs (see section 4.3.4).

4.4 Wastewater Situation

Stephan Wasielewski, Manuel Krauss, Ralf Minke

In the center village of Tupicocha, wastewater is arising from different sources, mainly toilets (private and public), kitchens and a slaughterhouse. The wastewater is collected in a sewer system and disposed outside the village without any further treatment. Currently, three different disposal sites are existing, all of which are hardly accessible. The wastewater is discharged into temporarily dry water bodies.

During a monitoring campaign in November 2018, flow rates ranging from 0.36 to 0.87 L/s (average: 0.6 L/s) were recorded from one of three disposal pipes (pipe below the village). Furthermore, chemical analysis was conducted on wastewater samples in November 2018 (Table 4.4). The samples were taken directly from the outlet at different day times to evaluate the changing composition.

» *Table 4.4: Chemical composition of the wastewater from Tupicocha (23.11.2018). Source: own measurements*

TIME	TOC	COD	COD (solved)	TKN	NH_4-N	P TOT	PO_4-P	NO_3-N	SUSPENDED SOLIDS
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
06:20	29	583	408	119	151.6	14.56	10.03	0.063	170
09:15	2	39	27	10	11.63	1.044	0.126	0.024	7
12:00	10	209	147	38	44.56	3.825	3.398	0.005	93
14:00	7	146	102	6	6.8	1.329	1.018	0.011	18
16:45	7	146	102	6	6.8	1.329	1.018	0.011	18
18:10	107	2131	1491	187	183	14.19	5.589	0.077	543
18:10a	24	479	335	102	119.5	5.7	5.308	0.056	40

a) Due to a peak in the flow rate (flush) the wastewater was diluted.

The wastewater was slightly alkaline (pH 7.7 to 8.8). The low COD (chemical oxygen demand) can probably be attributed to reduced use of detergents or hygiene products such as soap and shampoo. Furthermore, the high concentration of nitrogen compounds in the wastewater is striking. The high TKN (total Kjeldahl nitrogen)-concentration is probably due to additionally introduced liquid manure or similar animal excrements, e.g., from donkeys kept in the village. The solid-rich excrements of the animals are used as manure or farm manure, whereas the liquid part is disposed of via the sewerage system.

However, short-term shock loads are clearly visible in the relatively small sewer system. In the last sample (18:10a), relatively high concentrated wastewater (2 131 mg/L COD) was diluted due to a flush. In order to avoid overloading the wastewater treatment system, sufficient hydraulic reserves must always be provided to compensate for such shock loads.

From the determined composition of the wastewater, design parameters for the wastewater treatment plant were derived and listed in Table 4.5. Based on the drinking water demand, a daily wastewater volume of approx. 300 m^3 is expected.

» *Table 4.5: Design parameters for the wastewater treatment plant in Tupicocha*

PARAMETER	UNIT	VALUE
daily hydraulic load (Q_M)	m³/d	250
COD	mg/L	600
Suspended solids	mg/L	145
NO_3-N	mg/L	0
TKN	mg/L	86
P tot	mg/L	6.8

4.5 Integrated Concepts for Sustainable Drinking Water Supply and Wastewater Disposal

The aforementioned assessment of governance structure, drinking water supply and wastewater disposal situations, including water quality and risk analysis, formed the basis to develop integrated and sustainable drinking water supply and wastewater disposal concepts within the TRUST project.

These technical concepts aim to improve the water quality, to give access to safe and affordable drinking water (SDG 6.1), to facilitate access to adequate and equitable sanitation and hygiene (SDG 6.2), to increase safe reuse of wastewater for agricultural purposes (SDG 6.3), and to alleviate water scarcity (SDG 6.4).

The TRUST team developed concept drafts that were presented and discussed with local actors and water sector experts during workshops. The participation of local stakeholders and policy makers and the continuous discussion of the concepts with the local community lead to an iterative refinement of these concepts.

In the following, we describe the technical concepts for drinking water supply and wastewater disposal that we developed as well as the participatory formats of stakeholder involvement that we developed and conducted in parallel.

4.5.1 Technical Concept for Improved Drinking Water Supply
Stefan Stauder & Michael Hügler

Proposals for Optimization Measures

According to the results given in the previous sections, the existing water supply in Tupicocha is characterized by poor microbiological drinking water quality, which is encountered by the population by boiling the water. Furthermore, water quantity is an issue during the dry period of the year. A lack of trust in the institutions, e.g., the communal water organization, and cultural constraints such as a traditional habit to drink water only after boiling also need be taken into account.

As stated above, efforts should be made in the long term to protect the water resources, minimize the losses and to guarantee safe drinking water at the tap. However, this requires investments in adequate treatment measures and in a corresponding distribution network.

This situation is typical for many villages in the Andean region. Therefore, we propose a gradual optimization of the water supply for Tupicocha, which might be valid for many communities with similar boundary conditions.

As an initial step, the water quality needs to be improved. In doing so, the application of a cost-efficient and sustainable treatment technology is crucial. For example, highly sophisticated treatment methods common in Europe, such as membranes and flocculation, should not be considered. The availability of spare parts and consumables for these technologies cannot be guaranteed in rather poor and remote villages like Tupicocha. Instead, we propose the application of simple methods that can also be carried out by communal organizations in rural areas. As such, slow sand filtration (SSF) is the core treatment method of choice.

After successful implementation of this treatment method and demonstration of its efficiency to the inhabitants, i.e., robust and convenient operation and high-quality tap water (clear water, low turbidity, free of indicator bacteria), other optimization measures could be implemented step by step. This leads to the following chronology for the overall optimization of the drinking water supply:

1. Water treatment technology: Installation of an adequate water treatment technology, like slow sand filtration, and demonstration of its reliability by analyses of the resulting drinking water quality. We suggest combining these measures with a water saving campaign.
2. Protection of the raw water resources: Implementation of measures for the protection of the raw water resources (see also section 4.3.4).
3. Improvement and maintenance of the network and facilities: Improvement of the distribution network in order to minimize pipe breaks / water losses and to improve the hydraulic conditions. Adequate monitoring and maintenance of the facilities like reservoirs, transport pipes, storage tank and network.
4. Adaptation of the water reservoirs: Depending on the long-term consumer behavior, an extension of the central water storage capacity might be necessary.

Water Treatment Technology

As mentioned above, slow sand filtration is the method of choice in Tupicocha to remove particles including, e.g., chlorine resistant protozoa. The frequent cleanings of the existing storage tank (several times a year) indicate that after heavy rainfall high levels of solids/turbidity occur temporary in the raw water. Therefore, in the design of the SSF-unit a later addition of a simple pre-treatment by rapid sand filtration (RSF) should be foreseen. The main task of this RSF-unit would be to protect the SSF from high solid loads, therefore minimizing labor-intensive peeling of the upper sand layer of the SSF. For safety reasons - and to comply with Peruvian law - a final disinfection with chlorine should be foreseen.

The treatment plant should be constructed in the area above the current water storage tank. Consequently, the treatment can be operated by gravity, thus no pumps and energy for pumping are required. The following design (Figure 4.13) is based on a nominal throughput of 7 m^3/h, corresponding to 160 m^3/d. It could thus be operated to treat the expected total quantity of drinking water for the center village of Tupicocha (see section 4.3.1).

Rapid sand filter (optional)

The RSF unit is designed for a surface load of 6 m/h. For example, one rectangular concrete container (L x W x H = 1 x 1.2 x 2.5 m) could be constructed. At the bottom, a drainage system (pipes with nozzles or slots) has to be installed with two supporting layers of 0.15 m each (below: coarse gravel (10-15 mm) and above fine gravel (3-6 mm). The effective filter layer of 1.2 m coarse sand (1-2 mm) will be on top of these support layers. The throughput has to be adjusted by a valve and a water meter in the filter effluent. With the increase of the head loss, due to the accumulation of solid matter from the raw water, the height of the supernatant will rise. If it reaches the overflow (1.0 m above the upper edge of the filter material), a backwash in the upstream mode is required.

Backwash water tank for the rapid sand filter

The rapid sand filter has to be back-washed every 2 to 5 days, whereby a volume flow of 20 m^3/h is required over a period of 10-15 minutes. The minimum volume of the backwash water tank is therefore 6 m^3 and the tank should be arranged at a height of at least 15 m above the RSF. It is filled via a control valve from the raw water transport pipe (manual control).

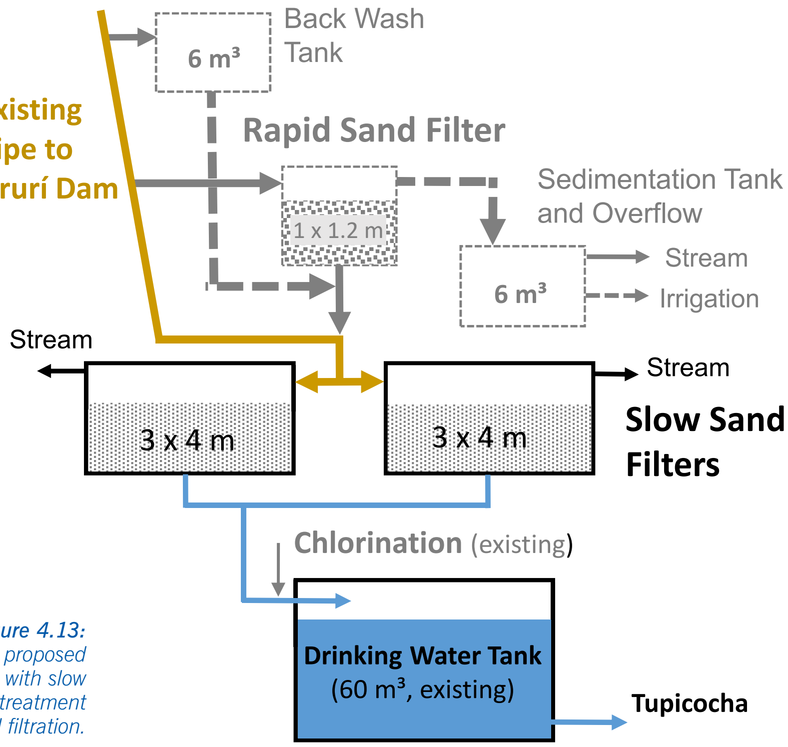
The used back wash water coming out of the RSF overflow should be fed into a sedimentation tank (volume 6 m^3) and from there, e.g., into an irrigation tank with overflow into a stream or rainwater canal. On the one hand, the backwash water (carrying the sediments that accumulated in the filter) is discharged via the overflow channel. On the other hand, in times with very high sediment load in the raw water (after heavy rain), the RSF will clog quickly, and the inflow is then automatically drained off via the overflow. Thus, the RSF has a double function in protecting the SSF.

Slow sand filter

The SSF system is designed with two lines and a surface load of 0.3 m/h. For example, two concrete tanks (L x W x H = 3 x 4 x 1.8 m) could be built. At the bottom, a drainage system (pipes with nozzles or slots) has to be installed with two supporting layers (below: 0.15 m gravel (4 - 8 mm) above: coarse sand (1 - 2 mm)). The effective filter layer above the support layers should consist of 1.2 m fine sand (0.3 - 0.5 mm). No backwashing is required for the SSF. Instead, the surface layer (approx. 0.05 m) must be removed in intervals of 2 - 4 months. This sand can be cleaned on site by manual washing and then reused in the SSF. De-aeration valves must be installed to avoid that air bubbles within the drainage system at the filter bottom clog the SSF. In addition, an overflow into a stream or rainwater canal has to be foreseen.

Disinfection

To disinfect the water, we propose to take the existing devices for dosing of hypochlorite solution into operation. Thus, the hypochlorite solution can be generated on site from inexpensive and durable calcium hypochlorite granules.



» *Figure 4.13:*
Schematic drawing of the proposed drinking water treatment process with slow sand filtration and optional pre-treatment by rapid sand filtration.

Maintenance

We estimate the following maintenance efforts:

- Daily: inspection, control; approx. 0.25 h
- 1-3 times a week: back wash of a RSF and control/adjustment and, if necessary, filling up of the chlorination system; approx. 1 h
- 3-6 times a year: peeling off and washing of the surface layer of one SSF; approx. 4-6 h
- Every year: renewing of one of the three filters (removing and washing of the filter material, refilling and, if necessary, topping up with new material); 1-3 days

Protection of the Raw Water Resources

A repair of the fencing at the inner catchment, e.g., the drainage field at the foot of Ururí dam, and a strict control of this area are imperative. In addition, the leachate intake should be modified so that the coverage of the water-bearing layer is increased. First of all, horizontal drainage pipes (perforated or slotted PE or stoneware pipe, inner diameter > 150 mm) should be dug in transversely to the seepage path. These pipes shall drain the water into a collecting shaft. Above the drainage pipes, sand with different grain sizes (depending on the slot diameter) has to be applied. In order to prevent surface water from entering the source, a water-impermeable cover layer (e.g., clay) must be installed.

As a compensatory measure, a field downstream of the fenced drainage area should be irrigated and animal troughs should be built nearby. Similar measures should be planned for other sensitive areas, in particular the lakefront area of the reservoir Tuctococha.

Improvement of the Drinking Water Network

Our data show a high drinking water demand in Tupicocha currently (e.g., due to permanently flushing toilets and further water losses within the distribution system).

Thus, as soon as major investments are made to improve the supply and, to provide a safe and high-quality drinking water, measures for better network maintenance and for minimizing water losses are required, in addition to a water saving campaign.

This includes improvement of the hydraulic conditions in the distribution network, as well as adequate monitoring and maintenance of the facilities like reservoirs, transport pipes, storage tank and network.

On the one hand, this saves the limited raw water resource and minimizes the operational expenses for drinking water treatment. On the other hand, a proper network is necessary to avoid secondary contamination of the treated drinking water during transport to the consumers.

Extension of Water Storage Capacity

As a rule of thumb, drinking water tanks should store a volume equivalent to at least an average daily demand in order to be able to buffer supply failures (e.g., pipe breaks). The existing water tank provides approx. 60 m^3 and therefore is rather small for the estimated average demand of 75 m^3/d.

Furthermore, a water tank with only one water chamber does not offer redundancy for cleaning or maintenance work. When the water tank is decommissioned, the inflow is limited by the treatment capacity of 7 m^3/h. This amount is not sufficient for peak demand. Therefore, the construction of a second drinking water tank should be foreseen on the long run.

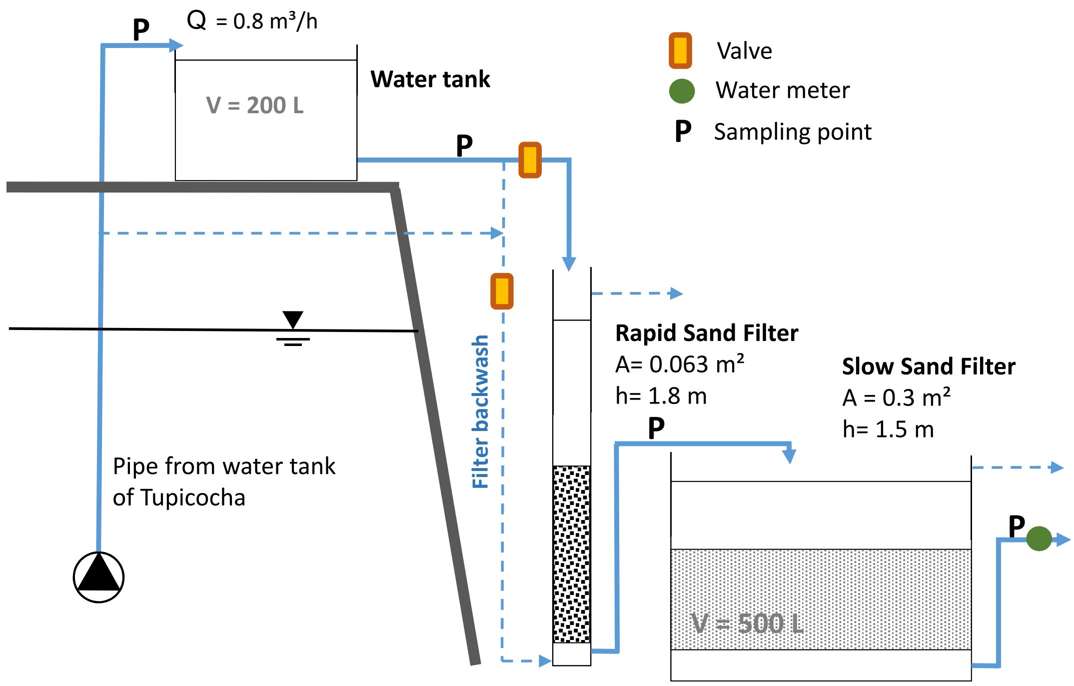
Energy Production

Installing a pump as a turbine in the feed to the drinking water tank might be an option for energy production.

Pilot and Training Plant for Drinking Water Treatment

As a first step for the implementation of the new concept for drinking water treatment, we developed a training and pilot plant, which is adapted to the framework conditions in the Andean highlands in general and to the situation in Tupicocha in particular.

The pilot plant (Figure 4.14) consists of three tanks connected in series with a volume of approx. 600, 100 and 1 000 L, respectively. The first tank serves as raw water reservoir. The second container is a gravel filter (cylindrical pipe, L = 2 m, DN 200). The outlet of this filter reaches the third container (1 000 L), into which an approx. 0.8 m high bed of fine sand is placed.



» *Figure 4.14: Schematic drawing of the pilot plant for drinking water treatment.*

The joint construction, together with the community of Tupicocha, was planned for spring/summer 2020. The pilot plant is an essential part of the training concept in order to explain and jointly refine the structure, operation and maintenance and to enable the future operators to carry out repair work and minor adjustments themselves.

Yet our plans had to be changed, due to the global COVID-19 pandemic that also affected Peru very seriously. Instead, the pilot plant was built and tested at TZW in Germany.

In addition to the scientific results that we expect from the construction and operation of the plant, transferable recommendations will be derived from the activities. These are intended to support local decision-makers, especially in highland communities in South America, who are striving for the implementation (planning, realization and operation) of an integrated concept for drinking water supply.

4.5.2 Technical Concept for Safe Wastewater Treatment and Reuse

Stephan Wasielewski, Manuel Krauss, Ralf Minke

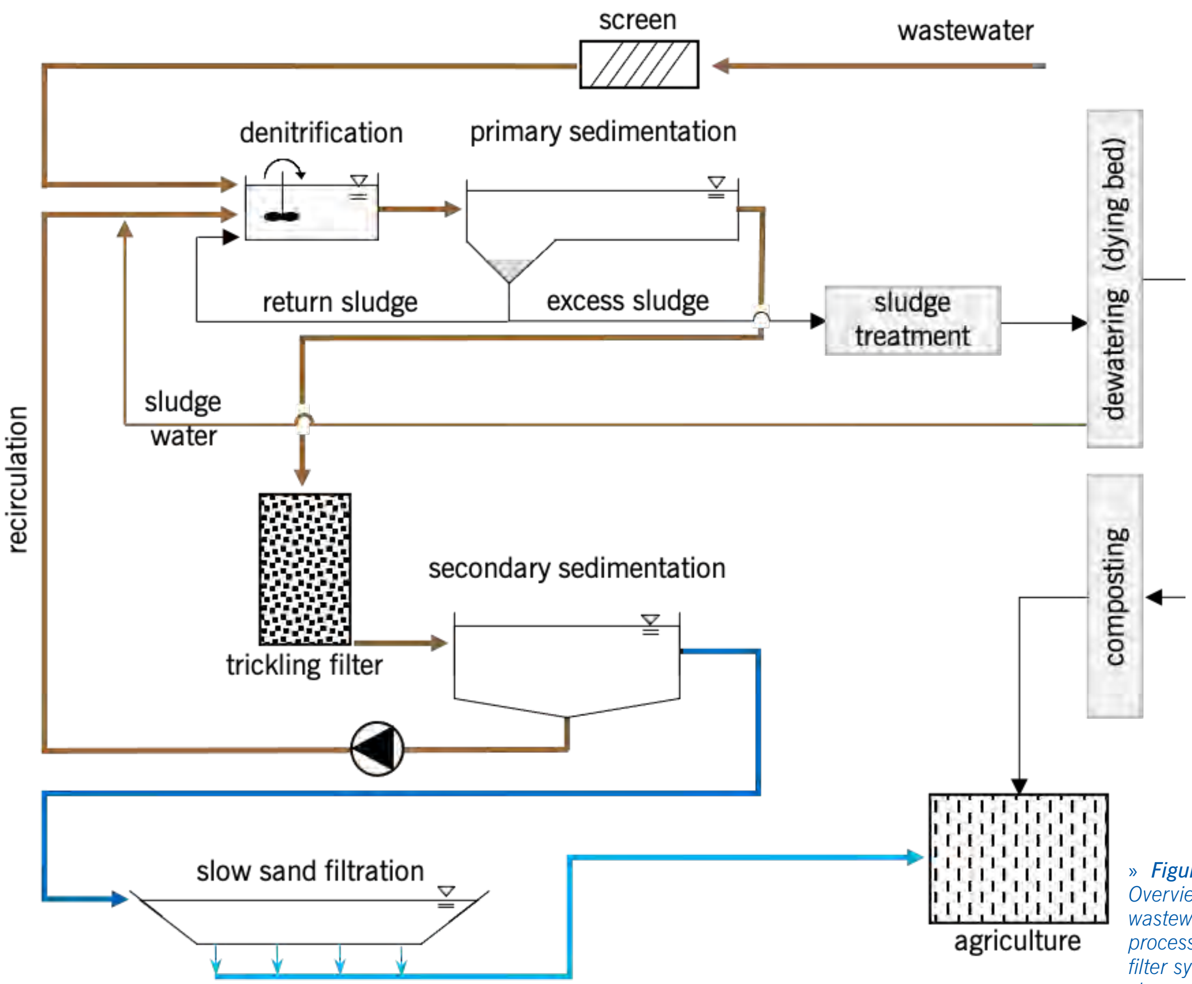
We have developed two concepts for safe wastewater treatment, one for small villages as Tupicocha and one for small homesteads as its anexos.

Proposal for Wastewater Treatment in Small Villages

Currently, the wastewater collected in the center village of San Andrés de Tupicocha is discharged into the environment without further treatment. In some cases, the untreated wastewater is taken from the receiving water body downstream, especially during the dry season, and used for irrigation purposes.

Therefore, a wastewater treatment system is proposed, which ensures the most energy-saving treatment possible by taking advantage of local conditions. In addition, the system must be robust enough to safely treat occasional slaughterhouse wastewater, arising mainly on weekends. By using the natural differences in altitude, the treatment system can be operated mainly by gravity.

For the treatment of the municipal wastewater a trickling filter system with an upstream denitrification is proposed (Figure 4.15).



» *Figure 4.15: Overview of the proposed wastewater treatment process with a trickling filter system followed by slow sand filtration.*

The wastewater is collected by the existing sewer system and discharged outside the village. There, coarse materials in the wastewater such as sand and gravel are removed by means of a screen and a sand trap. Additionally, grease is being removed. The sand can be washed and used, e.g., for road construction while the grease needs to be disposed.

The first tank will be used as a mixing and equalizing tank as well as a denitrification tank for the decomposition of carbon compounds. Nitrate as well as sludge will be recirculated together with the effluent of the trickling filter. Hereby, a significant reduction of COD can be realized which results in a smaller load of the subsequent treatment stages.

The denitrification tank is followed by a sedimentation tank, in which the suspended solids settle together with the biological sludge. Depending on the performance of the denitrification stage, the settled sludge must be pumped back, e.g., to ensure enough denitrifying bacteria and carbon sources (return sludge). In case that too much sludge is in this system, it can be removed as excess sludge and treated separately. For example, the excess sludge can be dewatered in a drying bed and composted. When composting, it must be ensured that the sludge is mixed with structuring materials such as straw to ensure aeration.

The effluent from the sedimentation, which is low in solids, is subsequently treated in a trickling filter with the aim of eliminating carbon and nitrogen compounds. In the upper zone of the trickling filter, which is predominantly populated by heterotrophic bacteria, nitrate is eliminated, e.g., in the deeper anoxic zones of the biofilm in the trickling filter. Depending on clogging of the trickling filter an occasional backwash is necessary to remove excess biofilm and ensure air flow. For this, supernatant from the subsequent sedimentation tank can be pumped to the top of the trickling filter.

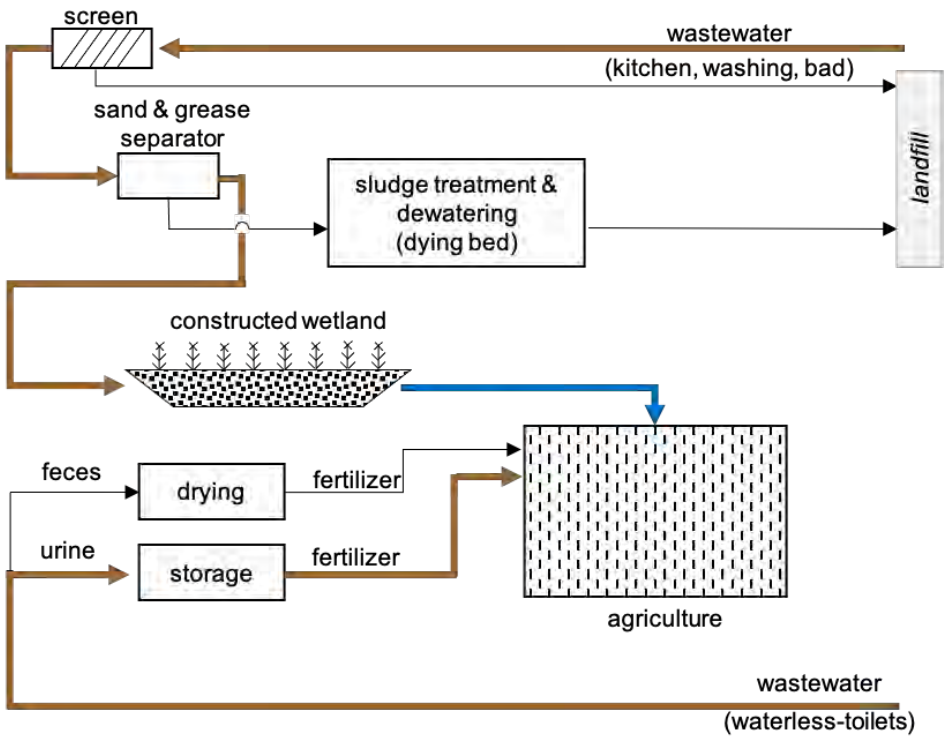
Excess biofilm, which is already sheared off in normal operation, settles in the subsequent secondary clarifier and is transported back into the denitrification tank together with the nitrate in the recirculation flow.

The treated and solid-free wastewater is passed through a slow sand filter to remove bacteria. If the slow sand filter loses its permeability due to the accumulating biomass, the top layer („Schmutzdecke“) can be removed mechanically.The treated wastewater can be used for irrigation in agriculture.

We planned a small pilot plant to treat 100 L/h (approx. 1/100 of the size of the final wastewater treatment plant). The denitrification and sedimentation tanks as well as the slow sand filter had a size of 1 000 L (Intermediate Bulk Container). For the trickling filter, two cylindrical water tanks of 1 200 L volume were stacked together. The bottom plate, which holds the trickling material (e.g., rocks, structural plastic media or plastic caps), was supported by steel bars. The sand filter was to be filled with a 60 cm sand layer.

Proposal for Wastewater Treatment in Small Homesteads (Anexos)

Small homesteads, also known as anexos, with only a few inhabitants are too far away to be connected to a central sewage system. Therefore, a separate treatment technology must be chosen for them, which is also low-maintenance but robust. For this purpose, we propose a concept that relies on source-separated sanitary facilities. The concept is depicted in Figure 4.16.



» *Figure 4.16:*
Overview of the proposed wastewater treatment concept with source separation of greywater, urine and feces.

Greywater arising from the kitchen, washing, and lavatory usually is less polluted. In this concept it is collected separately, sand and grease are removed and subsequently treated in a constructed wetland. For this purpose, known design values and existing experience with wetlands in the Andes region can be used. The effluent of the wetlands can be used for irrigation in agriculture. However, since only small numbers of inhabitants are living in the anexos, only a small amount of treated wastewater can be expected.

The flows of urine and feces are collected in waterless toilets. Feces are collected together with structuring materials such as straw or sawdust and composted. It is relatively easy to partially collect the urine in urinals. The long-term operation of these has already been successfully demonstrated in Peru.

Urine mainly contains nutrients such as nitrogen and phosphate, which can be used as fertilizer in agriculture after appropriate treatment. For treatment, the feces can be composited aerobically and the urine can be hygienized by storage (6 months) and afterwards used as fertilizer in agriculture.

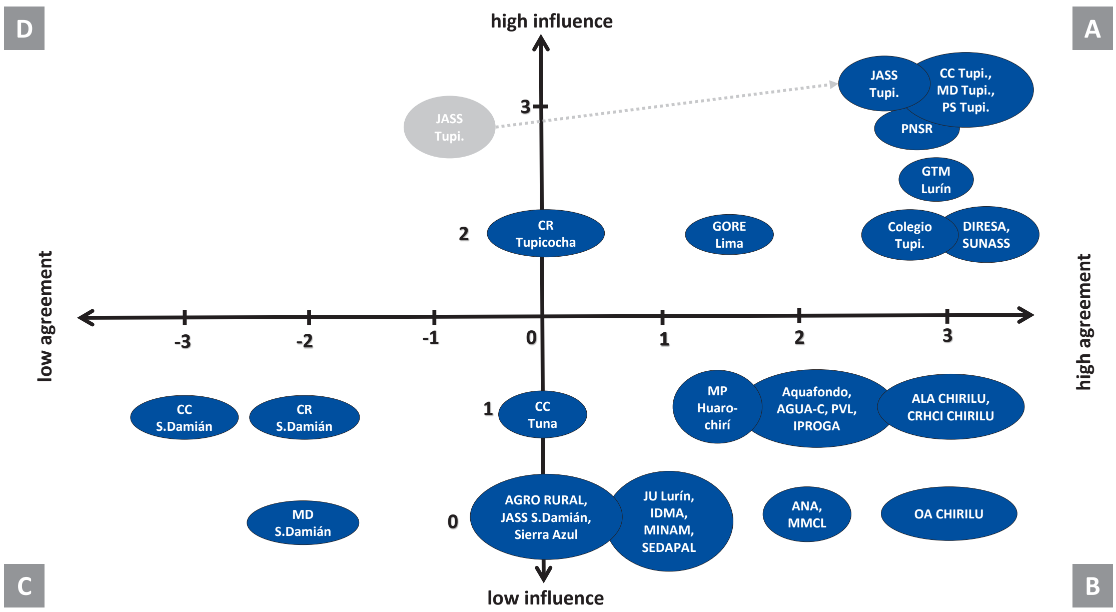
For a successful implementation of the concept, it is very important to involve the population into planning and implementation processes. In addition, training courses and workshops should be held to teach sustainable use of water resources and good hygiene practices.

4.5.3 Participatory Assessment of Technical Concepts

Yvonne Zahumensky, Fabienne Minn, Christian D. León

A fundamental and comprehensive stakeholder analysis was carried out (see section 4.2) to prepare a participatory assessment of preliminary draft versions of the two technical concepts described above. This participatory assessment served to revise and further adjust the developed concepts to local needs and conditions.

To plan the stakeholders' inclusion into the assessment of the proposed concepts, the actors have been grouped. This enabled the implementation of a previously developed participatory strategy for the subsequent participatory formats and stakeholder dialogues. To successfully involve the various stakeholders into the participation process, the most relevant actors were organized regarding their level of influence and agreement for implementing the new (waste) water concepts. This approach was based on a well-established method to structure stakeholder participation in international cooperation (GTZ, 2006). First, actors were rated in terms of their expected agreement with the implementation of innovative drinking water and wastewater concepts. Second, actors were rated regarding their actual influence, i.e., their power to negatively or positively influence decisions, regarding the implementation of such concepts. As a result of these evaluations, actors were positioned on a grid divided into four quadrants (Figure 4.17). This grid then informed the way in which the actors were involved further in the participatory process.



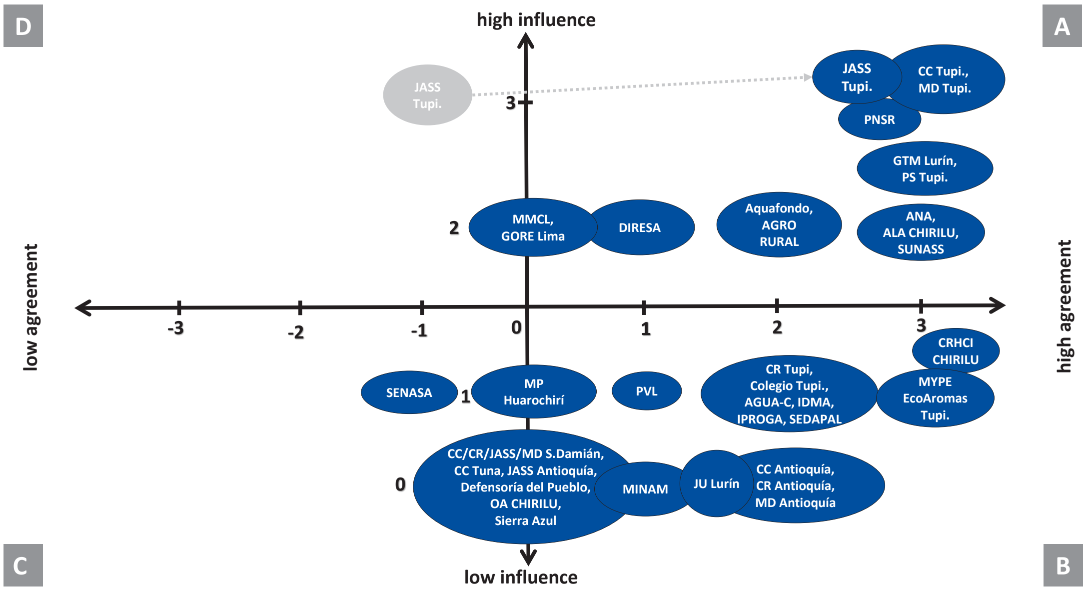
» *Figure 4.17: Categorization of actors in San Andrés de Tupicocha regarding the implementation of drinking water concepts (last update March 2020, for full designations, see text and list of abbreviations).*

Actors in quadrant A are key actors that need to be included in the participation process, also serving as potential partners to build bridges with other stakeholders. Although being less influential, actors in quadrant B can serve as important allies for implementing the concepts as well. Actors in quadrant C however, have rather lower influence and are expected to disagree. Hesitant actors in quadrant D have a higher influence and should be involved in the participation process to ensure that they have sufficient opportunity to express their concerns and explain their opposition. Considering the doubts, critiques and oppositions of the actors located in quadrants C and D can also provide valuable insights and contributions to developing adequate concepts.

This method also allows to display dynamic processes of change in actors' positions over time, as it was the case for the local JASS. Furthermore, the positions of several other actors were also slightly adjusted to reflect new insights. However, for a better readability of the figures, these minor changes are not depicted.

A large number of drinking water-related actors can be characterized as weak or not influential. Yet, the key actors, such as district municipality (MD), peasant community (CC), JASS, and health post (PS) can all be located within the most important quadrant A. The actors of this quadrant are assumed to be highly interested in implementing innovative drinking water concepts. Moreover, they are supposed to have a high degree of influence on local or even regional decision making with regard to water management.

Similar to the analysis of the drinking water actors, all relevant key actors regarding wastewater concepts can be clustered in quadrant A. It comprises those actors, who are assumed to show the highest degree of influence and agreement (Figure 4.18).



» Figure 4.18: Categorization of actors San Andrés de Tupicocha regarding wastewater concepts (last update March 2020, for full designations, see text and list of abbreviations).

In general, there are more actors involved in wastewater issues than in drinking water issues. This is due to the extended spectrum of potential users of (treated) wastewater and because wastewater concepts directly affect the villages downstream of Tupicocha. A large number of water-related actors are weak or not influential regarding wastewater. The majority of actors is assumed to have a more or less supportive attitude towards innovative water management concepts.

With regard to the reuse of treated wastewater it is shown once again, that the JASS is a key actor along with the municipality (MD) and the peasant community (CC). While the JASS was initially considered to take a skeptical position regarding new wastewater-related tasks due to its current lack of technical know-how, personnel and financial resources, the JASS can now be considered a motivated actor that is aware of the importance of this future additional task.

The majority of actors in Tupicocha are expected to have a rather positive attitude towards wastewater reuse concepts, also because they are assumed to lack (negative) experience with wastewater treatment concepts until now.

The participation strategy of TRUST focused on the proactive involvement, consultation, as well as partially on the close collaboration in particular with actors of quadrant A and D in several multi-stakeholder dialogue events (Figure 4.19), which are described in the following.

» *Figure 4.19: Local stakeholder workshop in San Andrés de Tupicocha. Picture: C. D. León.*

Development of an Adapted Participation Strategy

Categorizing relevant actors allowed the TRUST team to derive a participation strategy to obtain the stakeholders' evaluation of the proposed technical concepts. The overall strategic objective was to involve the relevant stakeholders into decision making, to prevent conflicts, to locally monitor and evaluate the technical concept drafts, as well as to increase their empowerment / ownership during possible future water management projects. From the experience of participative processes in Tupicocha, we identified three main aspects that should be considered before and during the dialogue events in rural communities: understanding, confidence and responsibility.

Understanding

The communal water organization (JASS) is a key actor both in drinking water as well as wastewater management and must be actively involved into the entire participation process (during all process stages and all topics). Arguments and challenges from the JASS' perspective should be made transparent for all participants - without the JASS running the risk of being pilloried.

Weakly connected actors (as civil society and state actors often are) should be motivated to increase their networking potential. The National Rural Sanitation Program of the Ministry of Housing, Construction and Sanitation (PNSR/MVCS) could play an important role in this regard, since it is a key actor who can provide opportunities for networking while enhancing its own relations with other (key) actors.

The stakeholders' awareness for the importance of the CRHCI CHIRILU, as a key actor should be increased. Its responsibility, know-how and potential to be an important ally should be put on the agendas of other key actors. Furthermore, the council's relations with other actors of the Lurín catchment should be strengthened.

Confidence
Increasing confidence and exchange between JASS and other key actors (Municipality with ATM, Comunidad Campesina, Puesto de Salud) was one of the most important dialogue objectives. Stakeholder dialogues should highlight the overall responsibility of the entire community – taking the JASS on board is essential, but not sufficient.

Processes and major results should be communicated clearly and timely to all participants of the dialogue events. It is important to pay attention to the level of communication, i.e., to differentiate between information of actors of the lower horizontal axis (quadrants B and C) and consultation processes with the actors of the upper axis (quadrants A and D) (two-way flow of communication).

Responsibility
The entire community should take responsibility for a potential technical solution. In this step, such participatory and cooperative methods are useful, which jointly define goals and tasks in a binding manner.

Actor groups with weaker means of articulation, e.g., women, should be motivated to actively express their interests. To foster such inclusive participation, the formats for expression need to be adapted to local social and cultural conditions. In addition, (participatory) methods that support the negotiation of goals, planning, and the allocation of tasks and responsibilities should be used with the aim to determine a binding, jointly agreed upon and manageable action plan.

Criteria for the Participatory Assessment of Technical Concepts

Two main participatory workshops with relevant stakeholders and experts have been realized: one stakeholder workshop in Tupicocha as representative location for the upper catchment area, and one expert workshop in Lima to include the views of water sector experts from national and international organizations. Both evaluation workshops took place in November 2018. In both workshops, the same two draft concepts have been presented and discussed. However, the participants differed significantly.

Discussions during these workshops served mainly to uncover the different preferences of different stakeholders and their evaluation of preliminary drafts of the TRUST drinking water and wastewater concepts (see above).

The fundamental outcome of the workshop was a list of evaluation criteria of the stakeholders and experts. These criteria later served to revise the TRUST water management concepts, as presented in 4.5.1. and 4.5.2. It was, thus, possible to revise and adjust the concepts according to local criteria as well as general up-scaling and transferability potential.

For the systematic evaluation of concept drafts, the TRUST team developed a qualitative assessment matrix (an adapted direct matrix ranking), which was used in both workshops. First, the two concepts to be evaluated were presented. Then, positive and negative statements regarding both concepts were collected and corresponding criteria were filtered out. The criteria were collected line by line on brown paper. This resulted in a matrix, where key statements were collected and the quality of the statements (positive „+“/negative „-“) were noticed in the matrix fields. Finally, comprehensive lists of evaluation criteria were compiled from the statements of the participants of both the stakeholder and the expert workshop.

In Tupicocha, the main objective of the stakeholder workshop was to evaluate concrete technical relevance and social acceptance of concept drafts for drinking water and wastewater treatment together with representatives of local organizations and authorities. All locally relevant stakeholders were invited to the evaluation workshop. Participants were the mayor, local councilors, the president of the peasant community (CC), the president and officials of the JASS, the president of the irrigation committee (Comité de Regantes), and representatives of the social program „Vaso de Leche“. During the workshop, the participants had the opportunity to assess the different concepts and to express their own preferences. Implementation potential and benefits of the developed concepts have been emphasized by the participants. On the evening before the evaluation workshop, a capacity building workshop on health, hygiene and water was held with the same actors. This capacity building workshop ensured that all participants of the evaluation workshop shared a similar knowledge base.

The expert workshop taking place in Lima brought together a group of representatives from public, private and civil society institutions as well as specialists for water and wastewater management from science and international cooperation. The main objective was to analyze and evaluate the concepts from a regional and national perspective. The workshop offered the participants the opportunity to evaluate the applicability of the concepts with regard to their socio-technical benefits, their financial feasibility and their potential for sustainable resource protection, as well as their transferability to other regional or even national river catchments with similar conditions.

» ***Figure 4.20:*** *Stakeholder workshop in Lurin. Picture: M. Krauss.*

Results from the Stakeholder Workshop in San Andrés de Tupicocha

The stakeholder workshop was able to build on a certain basis of confidence between the TRUST team and stakeholders which had already been established during prior visits and in particular during the previous evening. The workshop participants had received a brief introduction to the concepts the evening before and were familiar with the basic ideas. This had a positive effect on the understanding of the partly complex circulation systems and interrelations, and favored a profound and realistic evaluation of conditions, benefits, challenges, and obligations that were linked to the concepts by the stakeholders.

The following criteria were derived from the stakeholder workshop in Tupicocha. They indicate, how local stakeholders assess new water management concepts and what aspects they considered as especially important:

- Drinking water quality (e.g., protection of the water source, applying chlorine disinfection)
- Drinking water quantity (e.g., considering changing future demand)
- Wastewater quality (regarding reuse potential)
- Efficiency of water use (e.g., saving potential, water metering)
- Land requirements and consent of landowners
- Know-how (i.e., capacities and capabilities of operators)
- Acceptance (socio-cultural acceptability, awareness rising)
- Local ownership (regarding, e.g., operation, maintenance, responsibility)
- Financing (e.g., costs of system conversion, investments, water tariffs)

Results from the Expert Workshop in Lima

During the expert workshop that took place in Lima, the participants highlighted some aspects, such as cultural, social, institutional, financial and technical conditions that influence the applicability and functioning of the concepts. In the course of the discussion, the evaluations were systematically recorded. We derived the following central evaluation criteria (selection):

- Drinking water quality
- Adequacy with consumption patterns (current and future domestic, agricultural and industrial demand)
- Quality of sludge (to be disposed of or reused for energy production)
- Acceptance of innovative concepts (e.g., reuse of treated wastewater)
- Governance (regarding participation and capacities of stakeholders)
- Financing (including costs for maintenance and operation)

Overall, the experts insisted that innovative concepts have to be appropriately embedded into their contexts which present specific cultural, social, institutional, financial and technical conditions. Implementers must always consider specific regional or even local peculiarities.

All the criteria derived from both workshops with stakeholders and experts served to further evaluate, improve and adapt the drinking water and wastewater concepts to local requirements and to develop the final integrated TRUST concepts.

4.5.4 Evaluation of Developed Concepts with Regard to SDG 6
Hanna Kramer & Manuel Krauss

The developed technical concepts for drinking water treatment and wastewater disposal were evaluated regarding their contribution in achieving SDG 6 (see section 2.7 SDG 6 targets and indicators).

We carried out a classification according to the JMP structure of the drinking water and sanitation service ladders for the districts of Tupicocha. The current situation was evaluated based on national census data from 2017 (INEI, 2018) and own observations and calculations. The results are shown in Table 4.6.

» *Table 4.6: Classification of the district of San Andrés de Tupicocha into the Service Ladder Structure.*

SERVICE LADDER	DRINKING WATER	SANITATION
Safely managed	-	1.4 %
Basic	76.5 %	45.9 %
Limited	-	4.3 %
Unimproved	21.7 %	18.8 %
Surface water/ Open defecation	1.4 %	26.5 %
other	0.5 %	3.2 %

Indicator 6.1.1

The drinking water concept in Tupicocha was assessed on the basis of Indicator 6.1.1.

To evaluate the drinking water situation information about water quality is essential. However, only very limited data was available. Own measurements within the TRUST project have shown that the currently distributed drinking water from the reservoirs is frequently microbiologically contaminated. Furthermore, during the transect walk, local actors reported disease cases associated with contaminated drinking water (Kramer et al., 2020). This results in an assessment of the status quo as „unimproved“, although most households have direct access to drinking water through private or public taps.

The proposed drinking water concept could significantly improve the water quality. With the additional filtration, microbial contamination can be reduced. This ensures that households connected to the public network are provided with safe drinking water that meets the criteria of “safely managed” drinking water (Figure 4.21).

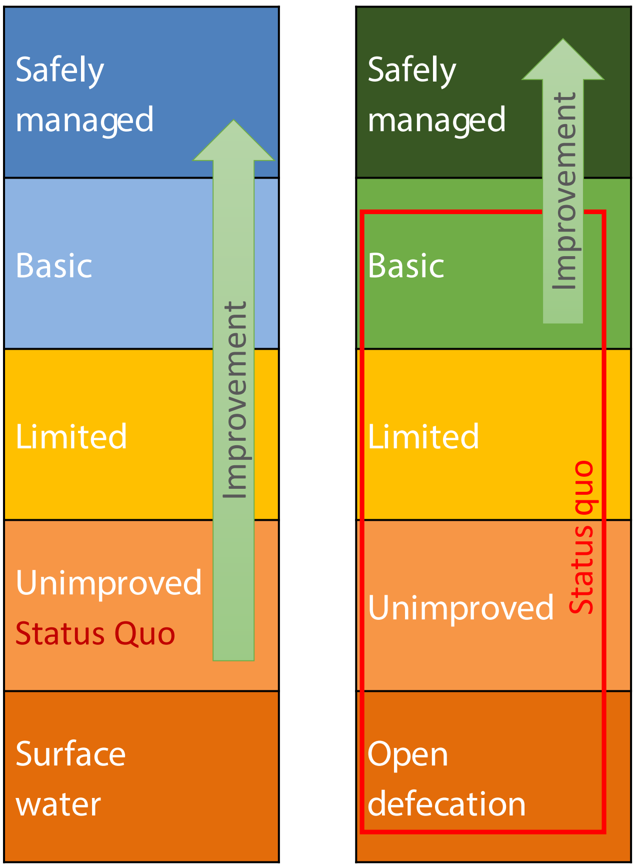
Indicator 6.2.1

For the assessment of the status quo on sanitation (indicator 6.2.1), the national census data provides a good overview of the type of sanitation facilities used and the degree of connection to a public sewage system. However, no information was available on whether wastewater treatment is being provided. In Tupicocha wastewater is not being treated. In addition, it could be observed that ponds and streams containing wastewater are used for irrigation.

The analysis of the status quo in Tupicocha showed that the situation varies greatly. However, the high percentage of the population practicing open defecation of about 26 % is striking. About 46 % have their own connection to a public sewer system. With the proposed wastewater concept, it can be guaranteed that excreta from households connected to the public sewer system will be safely treated. Therefore, this percentage could reach the top of the service ladder ("safely managed") (Figure 4.21).

Indicator 6.3.1

In Tupicocha there is currently no wastewater treatment, therefore the proposed wastewater concept would have a major impact on the situation, assuming that all households already connected to a sewer system will be connected to the proposed wastewater treatment plant. However, the losses due to leakage should be considered. Unfortunately, no data on the state of the public sewer system was available, therefore only estimates on existing leakage could be made. Assuming approx. 20 % leakage, 40 % of the generated wastewater of Tupicocha would be treated at the treatment plant.



» *Figure 4.21: Evaluation of SDG indicators 6.1.1. and 6.2.1 and improvement by the TRUST concepts.*

4.6 Interim Conclusions Upper Lurín Catchment

We analyzed the drinking water and wastewater situation in San Andrés de Tupicocha as a case study for a typical village in the upper catchment area of the Lurín valley. The water supply is based on a simple distribution system that supplies households with water from two reservoirs. In addition, spring water from local sources is used, which shows a good hygienic water quality, at least during the dry season. Wastewater is collected, but disposed without further treatment.

Hygienic issues arise from contaminations of the reservoirs, leading to fecal contaminations of the drinking water. Furthermore, wastewater is partially used for irrigation, representing an additional hygienic risk for the local population.

In a community-based approach we analyzed the situation and the challenges with regard to the drinking water and wastewater situation. We developed concepts for treatment measures and evaluated these concepts using participatory approaches with the local stakeholders and water sector experts. The main driver behind the concepts was the improvement of drinking water supply and wastewater disposal in order to progress in the fulfillment of the SDG 6 (safe drinking water and sanitation).


Picture: C. D. León

5. Lower Lurín Catchment: Urban Areas

Organizing authors: Manuel Krauss, Michael Hügler, Stephan Wasielewski

Picture: S. Wasielewski

5.1 General Overview

The lower part of the Lurín valley (districts of Lurín, Pachacámac, Cieneguilla, and Villa María del Triunfo) is characterized by urban settlements, agricultural land use as well as industrial areas. All these compete for the water resources. Water scarcity and quality are challenges in many sectors, such as agriculture, industry, human sanitation, and drinking water.

We investigated the status quo of the water resources (drinking water supply and wastewater situation), and carried out water quality analyses (microbiological and physico-chemical) of selected sampling points in the Lurín river, wastewater discharges, and groundwater wells. As a consequence of these investigations, the areas around the wastewater treatment plants (WWTP) Cieneguilla and José Gálvez were selected as examples for the development of new water reuse concepts as these areas are representative for the competing activities of different water using sectors in the lower part of the catchment area. To ensure future water supply of a growing number of inhabitants, without losing sight of environmental aspects, more efficient and sustainable concepts for drinking water supply and wastewater treatment have to be implemented.

Currently, between 45 % (Cieneguilla) and 57 % (Lurín) of the domestic water supply is covered by public network (INEI, 2017). Between 19 % and 48 % of the domestic water demand is met by water trucks or similar sources. The wastewater disposal by a sewer system is likewise distributed, with Cieneguilla (44 %) having the lowest and Lurín (58 %) the highest connection rate. Furthermore, the payment rate for the water service is high with around 90 %. The money for this service is payed to SEDAPAL (48 % to 77 %) or directly to the service trucks (22 % to 51 %).

Overall demand on water resources can be divided in three sectors: domestic, agriculture and industry. The total water demand in the lower catchment area is between 1.5 Mio. m^3/a (Cieneguilla) and 15 Mio. m^3/a (Pachacámac). Domestic water use (1.2 Mio. m^3/a) is the largest share in the demand of Cieneguilla whereas the main demand arises from irrigation in Pachacámac (11 Mio. m^3/a) and Lurín (3.5 Mio. m^3/a). Thus, domestic water demand, water for industries and irrigation in agriculture must be secured. The modular concepts aiming to reuse water in different sectors can contribute to meeting all water users' objectives.

5.2 Water Supply Situation
Stefan Stauder

The lower part of the Lurín valley is used intensively for agriculture and also has a dense, predominantly rural, small-town population but also larger urban centers towards the coast (e.g., the town of Lurín). There are extensive irrigation systems with extraction both from the Lurín river and from numerous wells. The drinking water supply for the inhabitants and for industry and commerce is also provided from local groundwater resources.

The exploited aquifer is about 50 to 90 m deep and consists of relatively coarse quaternary sediments. Since the precipitation rate is very low (< 10 mm/a), groundwater recharge occurs solely from the Lurín river, by bank infiltration and probably partly also because of intensive irrigation (e.g., infiltration from leaking canals). It must be mentioned that the Lurín river only temporarily contains larger amounts of water during the rainy season (December to March), when it rains more intensively in the upper catchment area. For the majority of the year, the infiltrating river water thus has a high share of untreated or insufficiently treated wastewater, or even consists exclusively of such water.

According to the documents provided by SEDAPAL, 22 deep wells (of 28 in total) were in operation in 2019 with flow rates between 5 and 41 L/s (mean value 21 L/s). The wells supply the larger communities, with chlorinated but otherwise untreated groundwater fed directly into the respective networks.

The wells are usually drilled with a diameter of 0.5 m to about 75 m below ground level (bgl). Filter tubes are installed from depths of 15 to 28 m bgl. According to the results of a pumping test at well No. 803 (Huertos de Lurín) in 2003, the idle water level was 6 m bgl and the drawdown increased from 10 m at 15 L/s extraction rate to 27 m at maximum extraction of 43 L/s. According to SEDAPAL, this is representative for the majority of the deep wells. For the years 2010 to 2017 the annual groundwater extraction of all SEDAPAL wells show a continuous increase from 8.6 to 11.2 million m^3/a (272 to 356 L/s).

Additionally, 1 783 so-called pozos terceros are located in the Lurín valley (SEDAPAL, personal communication, 2019). These are private as well as municipal wells from which groundwater is extracted for irrigation, for commercial and industrial water supply, and for the supply of smaller municipalities (in part also supplied by water trucks to higher situated municipalities). In 2018, the total extraction of these wells was around 21 million m^3/a or 670 L/s.

In total, about 30 to 35 million m^3/a of groundwater is extracted in the lower Lurín valley, exceeding the sustainable limit of 15 million m^3/a groundwater extraction, mentioned in a hydrogeological study commissioned by SEDAPAL (Coronel, 2012). According to the report, a tolerable annual withdrawal is leading to a lowering of the groundwater level by around 13 m by 2030, corresponding to a 25 % depletion of the total existing groundwater reserves. However, according to figures documented for 2017 and 2018, the „tolerable annual withdrawal“ of 30 million m^3/a has also been exceeded for some time.

Since numerous housing developments are being constructed, it can be anticipated that withdrawal rates will continue to rise. In this context, the project galerias filtrantes planned by SEDAPAL, helping to extract larger quantities of groundwater near the river next to the village Antioquia, also needs to be mentioned.

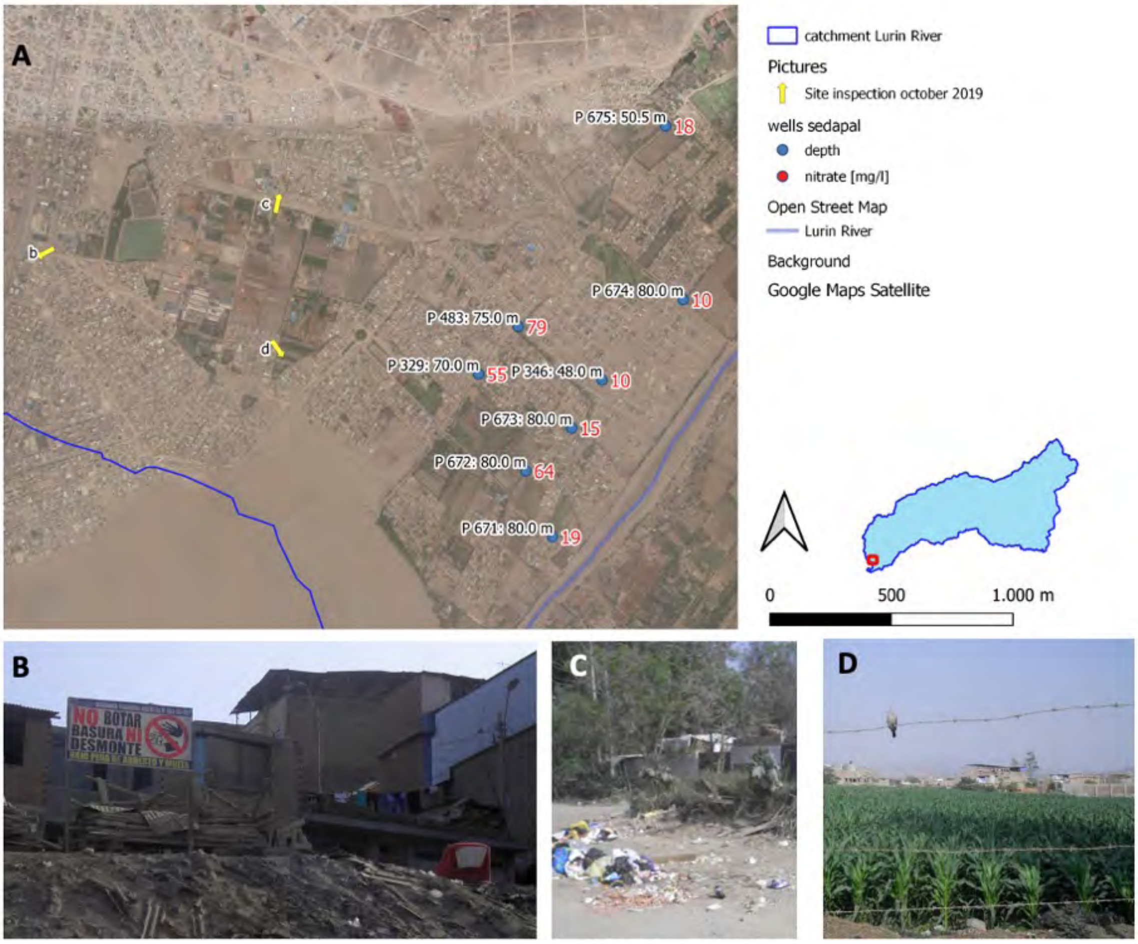
As a consequence of the overexploitation of groundwater resources in the Lurín valley, it is likely that shallower wells will dry up within a few years. Especially for groundwater from wells near the coast (District Lurín), an increase in salinity is also very likely.

5.2.1 Hazard Analysis and Risk Assessment

Thilo Fischer

Most of the information for the hazard analysis of the lower catchment has been deducted from Open Street Map and the aerial images of Google Maps. Furthermore, there has been an interview with a local expert of SEDAPAL and a site inspection of the area around the WWTP José Gálvez in October 2019. Additionally, SEDAPAL provided detailed spatial data of the wastewater collectors.

As already reported, SEDAPAL operates wells in the lower catchment with a depth between around 50 m and 80 m bgl. But the filter tubes begin at a lower depth (e.g., P 672 at around 30 m). The extracted waters from wells close to the WWTP José Gálvez have high concentrations in nitrate (Table 5.4). However, there is insufficient information about the specific area of this catchment. Therefore, the focus of the hazard analysis was on the estimated catchment of these wells (Figure 5.1). This analysis has a closer look at the Lurín catchment downstream from Cieneguilla instead. The groundwater catchment could have a different extent than the river catchment, though.



» *Figure 5.1:* *(A) Map showing nitrate concentrations in SEDAPAL wells (source: SEDAPAL), positions of hazards (yellow arrows) documented during site inspection in October 2019, (B) & (C) waste dump, (D) agricultural area. Pictures: T. Fischer.*

This region consists of urban areas including four wastewater treatment plants, farm land, hilly nature reserves, a quarry for the cement production and a few other industrial areas (pictures in Figure 5.1 and a map in Figure 5.2). The hazards derived from this land use are described below.

In the urban areas there are hazards to water quality due to car traffic like gas stations, garages, parking lots and roads where fuel or oil drip losses occur. Furthermore, there are also illegal open waste dumps that could leak a large variety of water-polluting substances (Figure 5.1 B & C).

Depending on the treatment efficiency of the wastewater treatment plants, the downstream river contains a large share of more or less treated wastewater. Thus, the concentrations of nutrient such as nitrates are elevated in the river water, especially during the dry season (Table 5.2).

Derived from a spatial intersection of the wastewater collectors and the urban areas, residential areas without connection to the sewer system were identified. People use drainless pits or rather just pits instead. If feces are not collected from the pits they might contaminate the groundwater. However, it must be taken into consideration that precipitation, which triggers infiltration, in the area is very low.

Furthermore, untreated wastewater is discharged from collectors directly into the river. For example, the village of Pachacámac discharges its wastewater directly into the Lurín (Torrico, 2018).

As a result of the low precipitation, particularly in the agricultural areas, irrigation of fields is done through many private wells. These wells are often not protected against flooding. In case of a flood this could lead to an intrusion of microbially contaminated flood water directly into the aquifer.

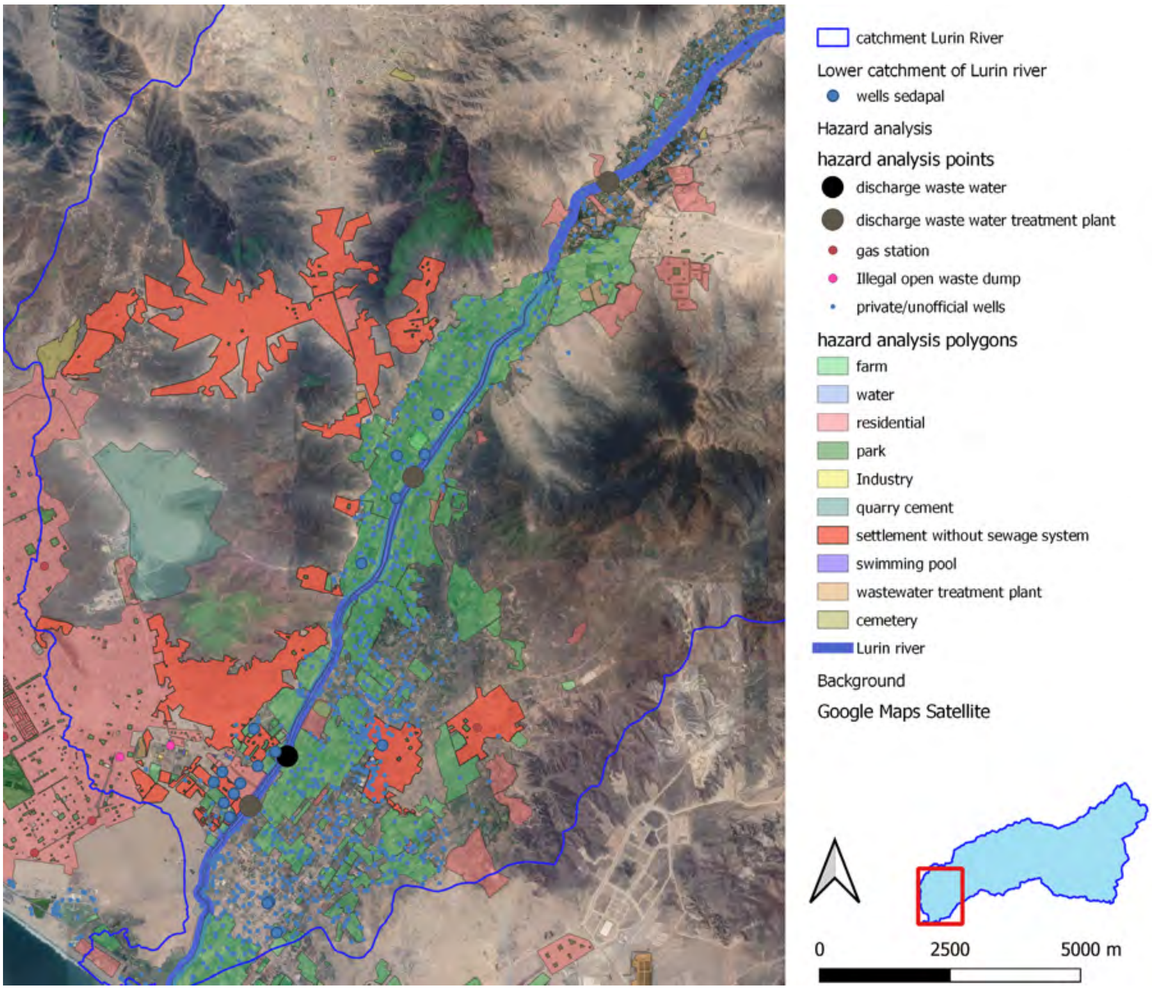
The effluent of the WWTP José Gálvez (Design flow rate = 100 L/s (SEDAPAL)) contains elevated values of nitrate and is used by residents for irrigation and fertilization purposes on farm areas (Torrico, 2018). Moreover, after a disinfection process the water is used for the irrigation of park areas (technical fact sheet on the website of SEDAPAL). Unused effluent is discharged into the river. On agricultural areas (Figure 5.1 C) pesticides as well as natural or artificial fertilizers are potentially used. As a consequence, from farm areas usually nitrate is emitted

Additionally, the sewer system of the settlements is a potential source of nitrate and microbial contamination in case of pipe leaks. The leachate from the sewer is emitted underneath the protective cover layer.

Table 5.1 gives an overview about the determined nitrate emitting hazardous events in the catchment area. Figure 5.2 shows the land use with respect to the aforementioned different hazards.

» *Table 5.1: Nitrate emitting hazardous events.*

LAND USE	HAZARDOUS EVENT
Farm area	Fertilization Irrigation with treated wastewater Irrigation with untreated wastewater
Park	Irrigation with treated wastewater
Settlement	Leaks in sewer collectors
Settlement without sewer system	Infiltration of feces in pits or rather potentially leaking drainless pits
River	Infiltration of river water with potentially high proportion of treated/untreated wastewater



» *Figure 5.2: Hazards in the ower catchment of the Río Lurín.*

As a result of nitrate infiltration in the catchment area, the concentration in the wells P 483, P 329, P 672 (Figure 5.1) is above the WHO guideline value of 50 mg/l (WHO, 2017). In the hazard analysis several nitrate emitting hazardous events were identified (Table 5.1). Especially wastewater (effluent of the WWTP José Gálvez with 100 L/s), that is used for irrigation and fertilization, has been identified as a hazardous event with a high risk and the main reason for high nitrate concentrations in raw water abstracted from these wells.

To tackle this hazard, a concept for an improved WWTP with a higher treatment capacity to remove nitrate as well as other contaminants, was developed (Chapter 5.4.3). As a result, the treated wastewater will be applicable to irrigate agricultural and green areas, without posing a risk of elevated nitrate concentrations in the groundwater.

Furthermore, it is not known to what extend other hazardous events contribute to the nitrate concentrations in the abstracted water from these wells. Currently, it cannot be predicted more accurately whether and to what extent nitrate concentrations will develop in the future. But, as mentioned above, due to the low precipitation in the area, there is no continuous trigger for an infiltration of the feces into the pits in the residential areas which are not connected to the sewer system. Therefore, the risk of this hazardous event is seen as being lower than the one through irrigation and fertilization with the output of the WWTP – but it is still slightly increased. The sewer system in the direct surroundings of the contaminated wells is documented to be in an excellent condition. However, the detailed spatial data of the wastewater collectors provided by SEDAPAL shows that north of the WWTP José Gálvez a large part of the system is in bad condition and in the west a large part is in regular condition. According to SEDAPAL, the direction of the groundwater flow in the area of the affected wells is mainly parallel to the river. But since there is no exact hydrogeological flow model available to exclude a hydraulic connection from the mentioned region (with collectors in bad condition) to the wells, the risk arising from the leachate of these potentially leaking collectors is still seen as slightly increased.

5.2.2 Water Quality of Ground and Surface Water

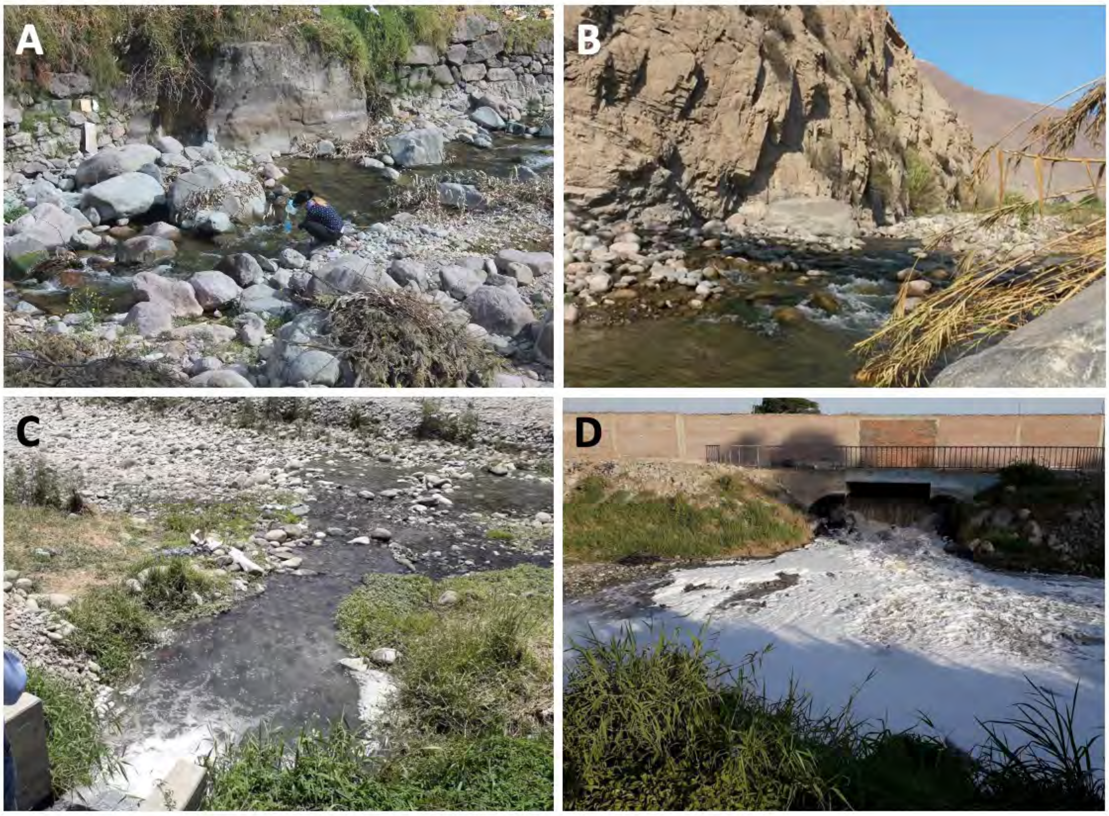
Stefan Stauder & Michael Hügler

In order to assess the groundwater and river water quality in the lower Lurín valley, available analysis data were evaluated and, in addition, physical-chemical and microbiological (including bacteriophages as viral indicators) analyses were carried out several times at a total of 18 sampling points between November 2017 and November 2019. With regard to a presumed influence of surface and wastewater, additional analyses were conducted for anthropogenic trace substances such as pesticides and active pharmaceutical constituents.

River water

The river water from the Lurín was analyzed at different locations:

- San Damián (3 200 m asl)
- Puente Antapucro (1 050 m asl, 15 km downstream of the village Antioquía)
- Cieneguilla (250 m asl, discharge point WWTP Cieneguilla)
- Quebrada Verde (approx. 8 km from the mouth)
- Fundo Santa Rosa, near the mouth of the Rio Lurín (5 m asl, discharge point WWTP San Bartolo)



» ***Figure 5.3:*** *Sampling points for the analyses of river water of the Río Lurín (A) San Damián, (B) Puente Antapucro (upper course), (C) Cieneguilla, (D) discharge point San Bartolo (lower course). Pictures: C. D. León (A), M. Hügler (B, C, D).*

» ***Table 5.2:*** *Selected analysis data of river water from the Río Lurín during the dry season.*

		SAN DAMIAN	PUENTE ANTAPUCRO	CIENEGUILLA	DISCHARGE SAN BARTOLO
Elevation	m asl	3 200	1 050	240	5
Electr. Cond. 25°C	µS/cm	326	660	1 170	2 690
Alcalinity pH 4,3	mmol/L	0.75	-	1.35	11.5
Calcium	mg/L	29.5	77	108	123
Chloride	mg/L	-	64.6	134	397
Nitrate	mg/L	-	5.1	97.7	< 0.5
Phosphorus, total	mg/L	-	-	11.2	-
TOC	mg/L	-	1.4	7.9	54
Copper	mg/L	-	< 0.01	0.01	0.02
Nickel	mg/L	-	< 0.001	< 0.001	0.005
EDTA	v/L	-	-	12	27
Acesulfame	µg/L	-	0.011	0.27	22
Carbamazepine	µg/L	-	< 0.01	0.095	0.14
Gabapentine	µg/L	-	< 0.01	< 0.01	3.9
Ibuprofen	µg/L	-	< 0.01	0.019	2
Iohexole	µg/L	-	< 0.01	0.075	6
Oxipurinole	µg/L	-	< 0.03	0.074	1.5
Sulfamethoxazole	µg/L	-	< 0.01	< 0.01	5.3

Figure 5.3 shows four of the sampling points at the Lurín river. Table 5.2 shows selected exemplary analytical data, Table 5.3 microbiological data. The obtained data indicate a good physicochemical composition of the river water at the upper course (San Damián and Puente Antapucro see Figure 5.3 A & B). The convcentrations of inorganic (e.g., calcium, chloride) and main organic constituents, like TOC, as well as the microbiological results were fluctuating within the usual range for river waters. Heavy metal or trace elements and anthropogenic trace substances (e.g., acesulfame, pharmaceutical agents) were not present in relevant quantities.

» *Table 5.3: Selected microbiological analysis data of river water from the Río Lurín.*

SAMPLING POINT	DATE	E. COLI	COLIFORM BACTERIA	ENTEROCOCCI	CLOSTRIDIUM PERFRINGENS	SOMATIC COLIPHAGES
RÍO LURÍN		MPN/100 mL	MPN/100 mL	CFU/100 mL	CFU/100 mL	PFU/100
San Damian	25.11.18	54	4 880	55	15	48
Antapucro	05.11.17	0	2 800	0	0	0
	10.11.17	97	10 100	210	0	2
	18.03.18	63	5 480	20	15	71
	10.06.18	3	2 420	2	0	0
	25.11.18	49	12 030	38	4	1
	31.03.19	50	1 730	29	3	13
	20.10.19	1	2 400	2	2	1
Cieneguilla	03.04.19	69	2 400	72	13	13
Quebrada Verde	03.04.19	308	6 490	65	890	93
Fundo Santa Rosa						
(before discharge WWTP)	03.04.19	480	4 100	29	1 800	180
(after discharge WWTP)	11.06.18	187 200	410 600	9 300	48 000	530 000
	27.11.18	125 900	488 400	3 600	40 000	200 000
River mouth	13.11.17	1 350	51 200	20	13 500	820

On the contrary, the results of the two lower monitoring points close WWTP Cieneguilla and WWTP San Bartolo outlets show a distinct anthropogenic influence (Table 5.3). This is due to the circumstance that the presented samples were taken during the dry season. As a result, the river water samples examined at these sites consisted almost entirely of the effluents of the respective WWTP. From the analytical values, it can be deduced that there are significant differences in the treatment efficiency of the two WWTP, Cieneguilla as well as San Bartolo and their associated catchment areas.

While at the effluent of WWTP Cieneguilla the TOC value was relatively low for wastewater and the nitrate value was elevated, the effluent from WWTP San Bartolo was nitrate-free but had a significantly higher TOC value. This indicates that the WWTP San Bartolo does not provide effective treatment (including effective oxygenation).

The significantly higher values for acesulfame and pharmaceutical active substances as well as for sodium chloride (NaCl) in the effluent of WWTP San Bartolo compared to the effluent of the WWTP Cieneguilla are probably due to the urban catchment area (Lima) of WWTP San Bartolo with a higher share of industrial wastewater. The low heavy metal contents are probably a consequence of the anaerobic treatment in which the heavy metals are precipitated as sulfides.

Especially in the lower course of the Lurín, the microbiological load increases continuously through the inflow of wastewater. In particular the discharge of the WWTP San Bartolo brings in enormous hygienic-microbiological contaminations.

Groundwater

We carried out extensive analyses on groundwater samples from eleven SEDAPAL wells and three irrigation wells in the lower Lurín Valley. Table 5.4 lists selected data from these analyses. Furthermore, data provided by SEDAPAL were evaluated. Furthermore, data provided by SEDAPAL were evaluated.

» *Table 5.4: Selected analysis data of SEDAPAL wells and dugwells (DW)*
(numbers in red = Peruvian drinking water limit exceeded, data: own measurements)

WELL			OXYGEN	PH	HARDNESS	BICARB.	SULFATE	CHLORIDE	NITRATE
		µmS/cm	mg/L	-	mmol/L	mmol/L	mg/L	mg/L	mg/L
315	Pachacámac 2	1 085	4.9	7.2	3.8	2.5	157	149	27
671	Villa Salvador P-1	673	4.8	7.2	2.4	2.5	-	-	-
672	Villa Salvador P-2	1 366	5.8	6.9	5.1	2.7	132	223	84
773	Cieneguilla 11	675	3.1	6.9	2.5	2.8	-	-	-
803	Huertos de Lurin 3	919	4.2	7.3	2.9	2.6	118	126	15
811	Nuevo Lurin 2	2 340	3.2	7.1	9.6	3.2	439	389	32
844	Tambo Viejo 3	718	3.1	6.8	2.8	2.8	-	-	-
861	Machay Bajo P-1	642	-	-	2.3	-	95	49	23
862	Picapiedra P-2	833	3.1	7.4	-	2.9	-	-	-
863	Manchay Bajo P-3	697	6.4	7.4	2.4	2.9	-	-	-
864	Manchay Bajo P-6	626	-	-	2.2	3.0	79	53	11
DW	Manchay, dugwell 1	818	-	7.83	2.9	2.5	-	-	-
DW	Manchay, dugwell 2	772	-	7.15	2.9	2.9	-	-	-
DW	Pachacámac	1 190	-	6.75	4.4	2.5	169	149	12

Table 5.5 shows the results of hygienic-microbiological water quality analyses of the groundwater at selected wells.

» *Table 5.5: Selected microbiological data of groundwater wells. (dugwells highlighted in blue, data: own measurements)*

WELL		TEMP. °C	TURBIDITY NTU	E. COLI in 100 mL	COLIF. BACT. in 100 mL	ENTEROCOCCI in 100 mL	CL. PERF. in 100 mL	SOM. COLIPH. in 100 mL
315	Pachacámac 2	24.3	<0.05	0	2	0	0	0
671	Villa Salvador P-1	24.3	<0.05	0	0	0	8	0
672	Villa Salvador P-2	24.3	<0.05	0	0	0	0	0
773	Cieneguilla 11	24.8	0.22	0	0	0	0	0
803	Huertos de Lurin 3	24.6	0.21	0	0	0	0	0
811	Nuevo Lurin 2	24.5	0.08	0	0	0	0	0
844	Tambo Viejo 3	24.7	6.0	0	0	0	0	0
861	Machay Bajo P-1	-	-	0	1	0	0	0
862	Picapiedra P-2	25.2	0.61	0	4	0	0	0
863	Manchay Bajo P-3	24.6	0.20	0	0	0	0	0
864	Manchay Bajo P-6	-	-	0	0	0	0	0
DW	Manchay, dugwell 1	23.7	0.88	26	287	7	1	0
DW	Manchay, dugwell 2	23.7	0.20	0	980	12	1	0

The main results of the analysis on groundwater from the SEDAPAL wells and dugwells in the lower Lurín valley can be summarized as follows:

- The groundwater is predominantly of good physical and chemical quality. It is sufficiently buffered, medium-hard and usually low in nitrate.
- The oxygen saturation is 20 to 50 %, thus, reduced impurities such as ammonium, Fe(II) and Mn(II) do not play a role. An exception is well 844, in which a mixture of oxygen-free, iron-containing and oxygen-containing groundwater is likely to occur. As a result, iron oxide hydrates precipitate, which is noticeable in a slightly increased turbidity.
- With regard to trace elements, only slightly increased contents of uranium and vanadium were detected in some wells (max. 9 and 8 µg/L).
- As expected, various anthropogenic trace substances can be detected in the well water, yet the concentrations are at a low level and thus unproblematic.
- Elevated nitrate levels are present in some well waters (max. 84 mg/L in well 672). This is probably due to the infiltration of insufficiently treated wastewater or its use for agricultural irrigation.
- The very low values for the organic sum parameters TOC and SAC254 as well as the very good hygienic-microbiological quality of the groundwater from all SEDAPAL wells should be emphasized. This shows that the bank filtrate or the seepage wastewater is effectively cleaned by the soil passage.
- The fecal indicators *E. coli,* enterococci and clostridia, as well as viral indicators were not detected in any sample from the SEDAPAL wells with one exception, well 671, where clostridia were present. This might be due to construction work that was done at well 671 during the sampling time. Thus, the overall hygienic-microbiological quality of the groundwater is very good and chlorination is an additional safety measure, protecting against potential contamination within the distribution networks.
- The increased salinity in some well waters (e.g., wells 811 and 315) is presumably not attributable to seawater intrusion, but to special geochemical conditions in the area of these wells. This is indicated by the elevated values for calcium and sulfate ions with relatively low values for sodium and chloride.

The photos on the following Figure 5.4 depict a typical SEDAPAL well in the lower Lurín valley.

» ***Figure 5.4:*** *Well head (left) and well building (right) of a SEDAPAL well. Pictures: S. Stauder.*

The three investigated dug wells (DW) also provide groundwater of a relatively good quality. The increased levels of fecal indicators (*E. coli,* enterococci and clostridia, see Table 5.5) are to be evaluated against the background that these are bricked, open wells (see Figure 5.5). The well „DW Pachacámac“ is located only a few meters from the Lurín river. During our sampling in the dry season, it contained reduced groundwater, recognizable by the slightly increased values for iron and manganese. During that time, the Lurín carried solely wastewater from the town Lurín.

» ***Figure 5.5.:*** *Open dug well in the lower Lurín valley (Manchay). Picture: M. Krauss.*

5.3 Wastewater Situation

Stephan Wasielewski, Manuel Krauss, Ralf Minke

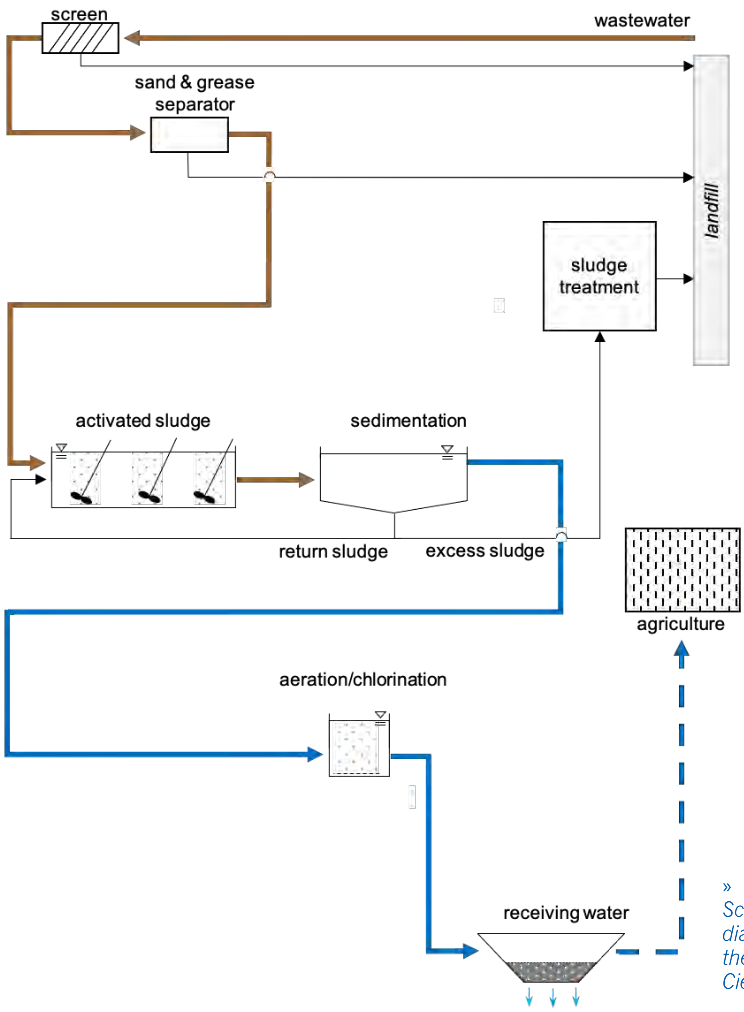
Wastewater is composed of used and disposed drinking water, feces, urine, and extraneous water (unaccounted drinking water, possibly infiltrating groundwater, as well as illegal discharges). In the study area (catchment of each WWTP), wastewater is collected in an underground sewer system and gravity-fed to the WWTP. In following, the disposal situation of the wastewater arising in the WWTP Cieneguilla and WWTP José Gálvez is described.

Study Area: WWTP Cieneguilla

In the case of the WWTP Cieneguilla, a high proportion of extraneous water could be calculated from both, the water consumption data and the inflow data of the wastewater treatment plant. Furthermore, the concentration of COD in the wastewater (from March to August) is very low (less than 300 mg/L), which is an indication of large amounts of extraneous water, e.g., due to groundwater infiltration.

The COD concentration, however, increases when the share of extraneous water decreases (September-December), indicating extraneous water arising from slightly contaminated rainwater or groundwater, eventually diluting the wastewater. Furthermore, wastewater from industrial processes or swimming pools could arise seasonally, too.

The WWTP Cieneguilla uses an activated sludge process (Figure 5.6). Wastewater is mechanically pre-cleaned by screens and (mineral) solids are separated in a grit chamber. Subsequently, the wastewater enters the biological treatment stage, consisting of a completely mixed and aerated rectangular tank (separated in two treatment lines). In the biological treatment stage, activate sludge is mixed and aerated by surface aerators. However, the areas between the aerators are not sufficiently aerated, resulting in presumably anaerobic zones. After the biological treatment the activated sludge is separated in a round secondary clarifier and returned to the biological treatment stage.



» *Figure 5.6: Schematic diagram of the WWTP Cieneguilla.*

The supernatant is disinfected with chlorine gas and subsequently fed into the Lurín river. Excess sludge from the process is removed, dried, and disposed.

Monthly random grab samples of both, inflow and outflow of the Cieneguilla WWTP are being taken and analyzed as part of the operational monitoring by SEDAPAL. Based on the measurement data provided (2014–2019, n = 38 data sets), a statistical evaluation was conducted.

Both, averages (COD: 105 mg/L, BOD: 29 mg/L, SS: 9 mg/L) as well as in 85-percentile values of all measurements (COD: 134 mg/L, BOD: 31 mg/L, SS: 13 mg/L) have been calculated. However, the concentrations are still too high for safe reuse of the wastewater. In addition, the effluent is microbiologically contaminated with thermotolerant coliforms (10^3 MPN/100mL).

As part of a monitoring program conducted by TRUST in cooperation with SEDAPAL, the daily course of the inflow of the WWTP Cieneguilla was sampled on a Tuesday (8/13/19) and a Saturday (08/17/19). For this purpose, 2-h composite samples were collected between 8:00 and 18:00 and subsequently analyzed.

The COD-concentration had a high variation between 500 mg/L and 800 mg/L over the weekend (here Saturday), with the pronounced concentration peak in the composite sample at 14:00. Nevertheless, the dissolved fraction of the COD has a constant concentration of about 300 mg/L, independent of the day and time. Likewise, the solids concentration is not subject to any pronounced fluctuation. Increased concentrations of the nutrients TKN and Ammonium are observed at the beginning of the day, both on weekdays (here Tuesday) and at the weekend (here Saturday) (approx. 100 mg/L TKN, approx. 50 mg/L Ammonium). The concentrations then decreased by half in the time between 7:00 and about 12:00 (approx. 50 mg/L TKN, approx. 25 mg/L Ammonium). The phosphorus concentration, on the other hand, is not changing significantly throughout the day.

Overall, the WWTP Cieneguilla achieves good results. It is a good basis for a potential safe water reuse, provided that lower effluent concentrations are achieved. This is addressed in the concept to retrofit the WWTP (chapter 5.4.2).

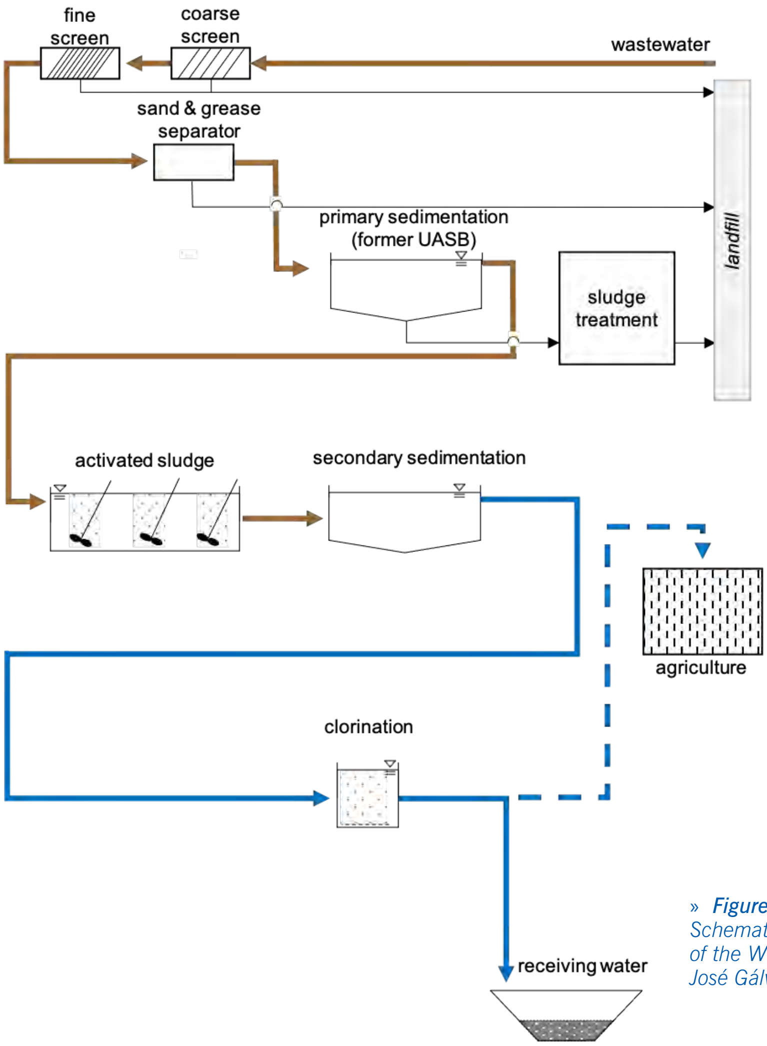
Study area: WWTP José Gálvez

In the WWTP José Gálvez municipal wastewater arising from households and small businesses of the nearby district is treated by means of aerobic and anaerobic ponds. A process diagram is depicted in Figure 5.7. Solids are removed by screens and a grit chamber. Subsequently, carbon compounds are eliminated in an UASB-reactor (UASB = Upflow Anaerobic Sludge Blanket). However, in 2019, it was out of order and used as primary clarifier instead. The pre-treated wastewater is fed into a completely mixed aerated pond (retention time approx. 1.8 d) for biological treatment. Sludge, formed from growing bacteria, together with treated wastewater, is afterwards fed into an anaerobic lagoon (hydraulic retention time about 5 d), where the sludge sediments and stabilizes. Finally, the treated wastewater is disinfected with chlorine gas. The effluent of the WWTP is used for irrigation of nearby agricultural and green areas. However, SEDAPAL reported that users are complaining about the water quality.

The data of the composition of the wastewater is based on monthly grab samples, which were taken, analyzed and provided by SEDAPAL.

Presumably, there is no infiltration of (ground) water into the sewer system ascribed to a deep aquifer and extremely low precipitation, resulting in low extraneous water content and a high COD concentration in the inflow (85-percentile: 1 394mg/L, average: 1 230 mg/L).

In the original design of the WWTP José Gálvez, COD removal by means of an anaerobic pre-treatment stage (UASB reactor) had been stipulated. This, however, is inoperative, probably due to hydraulic overload, and it is therefore used as a primary clarifier. An average high concentration of COD (483 mg/L), BOD (133 mg/L), SS (92 mg/L), and number of coliform bacteria ($4.2*10^6$ MPN/100 mL) in the effluent are an indication of an insufficient cleaning process. The Peruvian limit values are not met.



*» **Figure 5.7:** Schematic diagram of the WWTP José Gálvez.*

In addition to the data provided, as part of the TRUST project an on-site monitoring program was conducted (8/6/19 and 8/10/19) in cooperation with SEDAPAL, during which 2 h composite samples between 8:00 and 18:00 were manually collected from the inflow of the WWTP José Gálvez and subsequently analyzed.

Overall, the high concentration of the wastewater constituents is noticeable. Especially on Saturday, the concentration is subject to strong fluctuations (Fig. 7). The high concentration of COD at 8:00 (1 786 mg/L) and around 14:00 (2 648 mg/L) is notable. This can probably be attributed to the increased use of sanitary facilities in the morning and at lunchtime.

Furthermore, the nutrient parameters TKN (89-170 mg/L), Total Phosphorus (15.6-19.9 mgL) and Ammonium (35.6-65.7 mg/L) are also subject to a pronounced fluctuation. The high P-concentration can be attributed to the increased activity of commercial car washes and the use of cleaning agents.

Since the treatment performance of the WWTP José Gálvez is poor, a complete reorientation and conversion of the present WWTP is proposed (chapter 5.4.3).

5.4 Concepts for Sustainable Wastewater Treatment and Groundwater Recharge

In order to achieve safe wastewater reuse, qualified wastewater treatment forms the basis for the further infiltration of treated wastewater into the aquifer. Within this chapter, wastewater concepts for the two examples WWTP Cieneguilla and WWTP José Gálvez are presented in order to combine different possible use cases:

1. In the case of the WWTP Cieneguilla, it is possible to improve the quality of the effluent through systematic upgrading of the plant technology and process control to such an extent that reuse is possible. The area is particularly characterized by a strong seasonality in water consumption. Seasonal fluctuations can be balanced out and re-use potentials can be better exploited through better treatment and reuse (Chapter 5.4.2).

2. In the case of the WWTP José Gálvez, a complete re-planning is necessary due to the overload of the existing plant technology and the insufficient cleaning and odor of the wastewater. In this case, a wastewater treatment plant can be built, which enables the reuse of the waste water due to its high purification capacity. The cleaned water could also be used either to enrich the aquifer or for irrIgation in the nearby agriculture (Chapter 5.4.3).

5.4.1 Groundwater Recharge

Stephan Wasielewski, Stefan Stauder, Michael Hügler, Manuel Krauss

Groundwater recharge with treated wastewater is an economic and ecologic method for wastewater reuse since, when properly designed and managed, pathogens, bulk organic matter, nitrogen and organic micropollutants are removed (Sharma & Kennedy, 2017).

Taking the legislation of various countries and institutions such as the WHO, EU, Germany and USA as an example, the most common objective of all is to protect groundwater or to prevent pollution in groundwater. Groundwater, recharged with treated wastewater, should not need supplementary treatment after extraction (WHO, 2003a), hence the water quality before injection in the aquifer should meet drinking water quality.

The pollution by pathogens such as bacteria, viruses and protozoa directly influence groundwater quality. These pathogens represent by far the most important risk factors when producing drinking water (Asano & Cotruvo, 2004). Intensive pretreatment is necessary to avoid possible waterborne disease outbreaks (Masciopinto et al., 2008).

Physical parameters including pH, total suspended solids (TSS), total dissolved solids (TDS) and chemical parameters including organic carbon, nitrogen (ammonium, nitrate, nitrite) and total phosphorous (TP) should be considered carefully because of clogging problem in recharge system. TSS will cause physical clogging in recharge systems and cause decreasing rates, TDS can be used as a potential indicator of chemical clogging (by precipitation), and organic carbon, nitrogen, and TP as nutrients will affect the growth of microorganism, which will cause biological clogging in recharge wells (Jeong et al., 2018).

Furthermore, dilution with groundwater is important for artificial recharge, leading to reduction of the contaminant concentration. Due to dilution with native groundwater, a change in the concentration of dissolved solids (Vandenbohede et al., 2008) as well as a reduction of nitrogen compounds has been reported (Lasagna et al., 2013). However, this phenomenon is omnipresent and is not affected by the biological and chemical conditions in groundwater (Lasagna et al., 2013). Rather, despite dilution, DOC was also removed by artificial groundwater recharge (Amy & Drewes, 2007),

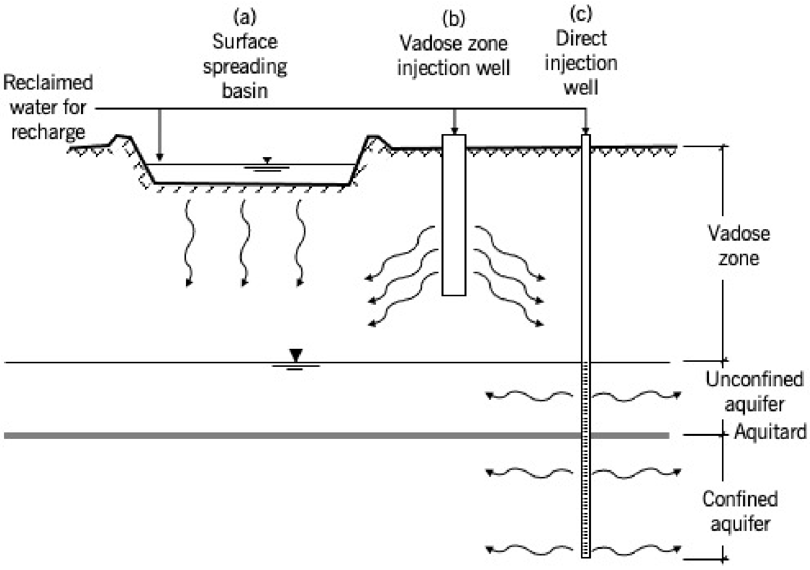
Recharge water is advised to meet drinking water quality to prevent pollution in groundwater (WHO, 2003a; TrinkwV, 2001; EPA/600/R-12/618, 2012). The advised water quality is listed in Table 5.6.

» ***Table 5.6:*** *Advised water quality comparison of WHO, Germany and USA for artificial groundwater recharge.*

		UNITS	WHO (WHO, 2017)	GERMANY (TRINKWV, 2001)	USA (EPA 816-F-09-004, 2009)
Physical parameters	pH	—	6.5-8.5	6.5-9.5	6.5-8.5
	TSS	mg/L	—	—	<5
	TDS	mg/L	<600	—	<500
	Cl-	mg/L	<250	<250	<250
Chemical parameters	SO_4^{2-}	mg/L	<250	<250	<250
	TOC	mg/L	—	—	<2.0
	NH_4^+	mg/L	—	<0.50	—
	NO_3^-	mg/L	<50	<50	<44
	NO_2^-	mg/L	<3.0	<0.5	<1
Pathogens	*E. coli*	number/100 mL	0	0	0
	Enterococci	number/100 mL	—	0	—
	Viruses (enteric)	number/100 mL	0	—	0
Trace organic compounds	Atrazine	mg/L	0.1	—	0.003
	Trihalomethanes	mg/L	—	0.05	0.08
	Haloacetic acids	mg/L	—	—	0.06
Trace elements	F	mg/L	<1.5	<1.5	<2.0
	B	mg/L	<2.4	<1.0	—
	Fe	mg/L	<0.3	<0.2	<0.3
	Mn	mg/L	<0.1	<0.05	<0.05

Organic micropollutants, e.g., from cosmetics and pharmaceuticals, are being removed in advanced wastewater treatment plants (WWTP) by means of processes such as adsorption on activated carbon, microfiltration, nanofiltration, and reverse osmosis (Asano & Cotruvo, 2004). However, the toxicology characteristics of most trace organic compounds and their metabolites are not recognized and the long-time influence of the compounds to people's health is not well understood. Therefore, most trace organic compounds are not limited in practice.

Three different types of recharge systems are illustrated in Figure 5.8. Recharge systems, such as surface spreading basin (a) and vadose zone injection well (b), are restricted by soil permeability. The recharge water in the two systems can only reach unconfined aquifer. On the contrary, a recharge system by a direct injection well (c) is independent on soil permeability, thus recharge water can reach both unconfined and confined aquifer. Recharged water from both, surface spreading basin and vadose zone injection well, passes through the vadose zone, therefore, usually a better removal efficiency is achieved by the two systems compared to direct injection well.



» Figure 5.8: Three different aquifer recharge systems with treated wastewater; (a) surface spreading basins (b) vadose zone injection well (c) direct injection well (EPA/600/R-12/618, 2012)

Groundwater Recharge in the Lower Lurín Valley

Currently, the groundwater extracted from most wells for drinking water production still has a very good physical-chemical and microbiological quality. However, locally elevated nitrate concentrations and findings of anthropogenic micropollutants are a clear indication of an interference by untreated or insufficiently treated wastewater, as was to be expected due to the hydrogeological and water management situation described above.

In order to ensure the long-term quality of the groundwater in the lower Lurín valley, qualified treatment of municipal and industrial wastewater is required before it is discharged into the Lurín (target value lower than ECA Peru). The wastewater treated in this way would then be discharged into the Lurín river as it is current practice today and from there naturally infiltrate the aquifer or be used for irrigation in agriculture.

A further improvement of the groundwater quality, as well as an increase of the usable groundwater quantity, could be achieved by advanced treatment of the wastewater and using it together with river water (in the rainy season) specifically for artificial groundwater recharge. The quality objectives of this advanced wastewater treatment should be based on the technical requirements (e.g., minimized colmatation) and the efficiency of the cleaning and dilution processes during the subsequent underground passage (hygienization, degradation of carbon and nitrogen compounds).

At the moment, it is estimated that the use of simple and cost-effective processes such as flocculation filtration and artificial groundwater recharge will be sufficient. This assessment is based on many years of industrial-scale experience in the production of drinking water from surface waters influenced by wastewater in Germany. The use of complex and relatively expensive treatment technologies, such as membrane and oxidation processes, should be avoided wherever possible. Further considerations should be based on the following concept for artificial groundwater recharge in the lower Lurín valley:

1. qualified wastewater treatment (see wastewater concepts below; to a NH_4^+ effluent concentration of 0.4 to 0.8 mg/L)
2. hygienization (e.g., through chlorination / chloramination), e.g., by addition of 2-8 mg/L chlorine, static mixing, 2 to 3 min reaction time)
3. flocculation/precipitation: Addition of 2 to 10 mg/L Fe (III) and static mixing
4. rapid sand filtration: e.g., grain size 1-2 mm, filter height 1,2-1,8 m, surface load 6-12 m/h, rinsing: Air-Air/Water-Water, Rinsing water demand < 3 %)
5. infiltration systems (artificial basins or ditches and/or river bed)

On the basis of literature references, the area required for artificial infiltration basins can be estimated at approx. 20 m^2 per 1 L/s. To achieve an infiltration rate of 25 L/s, infiltration basins with a total area of approx. 500 m^2 would have to be constructed and intermittently fed with treated wastewater. Additionally, it is also possible to use the river bed of the Lurín river for artificial groundwater recharge during the dry season (see Figure 5.9).

» *Figure 5.9: Riverbed of the Lurín close to well P-861 (near Manchay, November 2018). Picture: M. Hügler*

This concept has to be checked, and, if necessary, modified in the course of a pilot operation by means of appropriate monitoring. With regard to anthropogenic trace substances, monitoring and risk assessment according to WHO should also be provided.

5.4.2 Technical Concept for Wastewater Treatment (Retrofit of WWTP Cieneguilla)

Stephan Wasielewski, Manuel Krauss, Ralf Minke

The following cleaning objectives by using and expanding the existing building structure of the WWTP Cieneguilla shall be achieved:

1. safe compliance with the existing Peruvian limit values for the discharge of treated wastewater into receiving water bodies
2. safe reuse of the treated wastewater as irrigation water for agriculture
3. safe reuse of treated wastewater for artificial groundwater recharge.

Since only very little hydraulic peak loads from rainwater are expected, the maximum hydraulic load within 2 hours, $Q_t = Q_d/12$, is assumed as the maximum inflow (= 864 m^3/h). To avoid hydraulic overload of the treatment plant in case of heavy rainfall events, e.g., due to the El Niño phenomenon, a combined sewer overflow must be provided at a suitable point.

Activated Sludge Process

The process scheme of the existing treatment plant as well as the composition of the wastewater and the daily loads to be treated are described in Chapter 5.3.

The biological stage of WWTP Cieneguilla is relatively large-scale (V = 10 000 m^3). Based on the design according to DWA-A 131 (2016) only one third of the volume (2 828 m^3) are required. Hence, large operational reserves are available. However, spiral aerators as well as surface aerators are currently used, which probably dissolve less oxygen compared to membrane aerators. Due to the large (and oversized) tank volume, sufficient buffering and a high sludge age (about 18 days) is achieved. In contrast, the design according to DWA-A 131 (2016) shows that a much lower sludge age of two days is sufficient for the desired removal of organic carbon compounds.

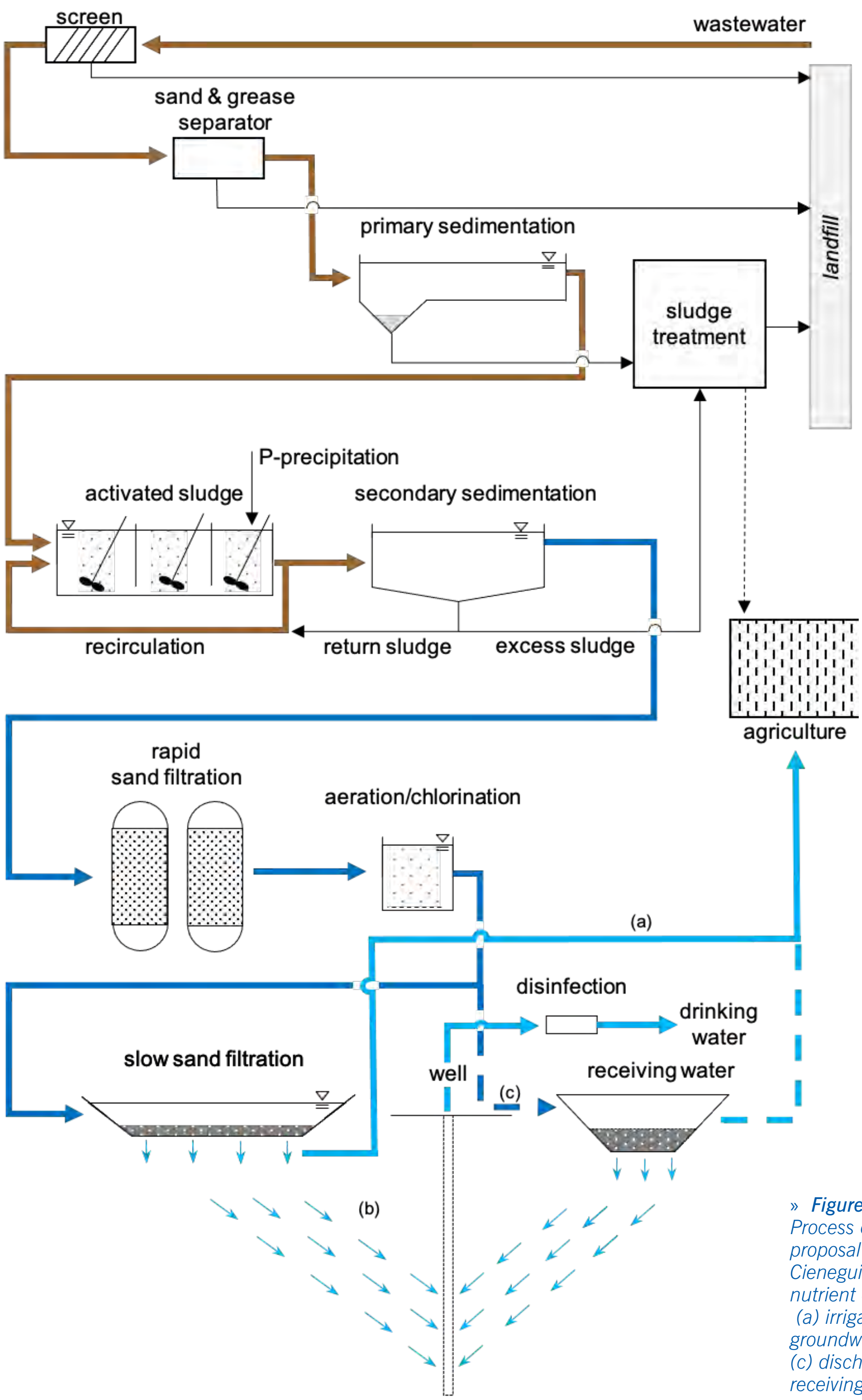
Improved Activated Sludge Process

Figure 5.10 shows the concept of the treatment process. Due to the size of the current activated sludge stage, a systematic nitrification and denitrification can be achieved by modifications, e.g., by installing barriers.

Initially, the wastewater is passed over a screen and coarse material is removed. In a subsequent grit trap, mineral solids with a high density are separated. Coarse materials as well as sand should be disposed of as waste in accordance with Peruvian requirements, whereby any remaining organic matter, sludge or similar should be washed off or removed. The resulting washing water can also be treated in the WWTP.

A primary sedimentation tank with a hydraulic retention time of one hour is provided to relieve the biological stage from suspended solids and organic compounds. This volume could be provided in a relatively simple and cost-effective way by modifying, i.e., reducing the size of the current activated sludge tank. The primary sludge can be treated together with secondary sludge in an anaerobic digestor to harvest biogas for energy production. In the AS stage defined anoxic zones (< 1 mg/L O_2, nitrate is present) are provided for denitrification. By the installation of barriers, a controlled flow can be realized. The low-oxygen wastewater from the primary treatment is fed into the first denitrification zone and subsequently into an aerated nitrification zone (> 3.0 mg/L O_2).

This process is repeated alternately. The nitrate-rich effluent from the biological stage (mixture of partially treated wastewater and activated sludge) is recirculated to the denitrification zone. A sufficiently large distance between the aerobic and anoxic zones must be ensured. In the secondary sedimentation tank the activated sludge flocs are separated and the supernatant is afterwards disinfected by chlorine addition. Both, the Peruvian limits for discharge into a surface water body and for use for irrigation will be met. A corresponding discharge or sale of the water is therefore possible.



» *Figure 5.10: Process concept proposal for WWTP Cieneguilla with further nutrient elimination for (a) irrigation, (b) artificial groundwater recharge or (c) discharge in receiving water.*

Furthermore, the effluent could be used for artificial groundwater recharge to an even greater extent. However, more extensive treatment is recommended to protect the infiltration facilities. On the one hand, a more extensive denitrification should be aimed at e.g., by adjusting the oxygen input in the biological stage. On the other hand, according to current estimates, an expansion of the treatment technology as well as the construction of a rapid sand filtration to remove particles (to avoid clogging in subsequent irrigation application or artificial groundwater recharge) is necessary. Precipitation/flocculation is conducted to remove phosphate by adding iron or aluminum salts by admixing the precipitants either to the primary sedimentation tank, or the AS stage, or the secondary sedimentation tank. For the treatment of a nominal volume flow of 864 m^3/h, for example, a rapid sand filter unit consisting of 5 squared overflow filters with a surface area of 15 m^2 each could be constructed and filled with a quartz sand layer approx. 1.5 m high.

The excess sludge produced is stabilized in drying beds and can be utilized as a fertilizer in agriculture, for example, if Peruvian limits are met. Considering the current sludge treatment - partial aerobic stabilization in the wastewater treatment process and subsequent aerobic treatment with solar drying, where no liquid material flows occur, no back load was considered as no anaerobic processes occur, in which ammonium is released.

With regard to a modular implementation, it is recommended to first optimize the aerators and flow conditions and only implement an extended conversion when it is foreseeable that the population and tourism will increase according to the planning scenario.

5.4.3 Technical Concept for Wastewater Treatment (Retrofit of WWTP José Gálvez)

Stephan Wasielewski, Manuel Krauss, Ralf Minke

The current effluent quality of the WWTP José Gálvez is poor (site inspection in 2019), since the discharged effluent from the WWTP does not comply with the limit values in Peru. Therefore, the aim of the wastewater concept is to achieve the following cleaning objectives by planning and designing a new WWTP:

1. compliance with the Peruvian limit values for the discharge of treated wastewater into receiving water bodies,
2. safe reuse of the treated wastewater for irrigation in agriculture,
3. safe use of treated wastewater for artificial groundwater recharge.

The implementation of the new WWTP is to be done in several treatment lines. Based on forecast data (provided by SEDAPAL), the dimensioning is done to 150 L/s, however, for the year 2039 an inflow of 250 L/s is predicted. By adding one or more treatment lines, the additional arising wastewater could be treated if necessary in the future.

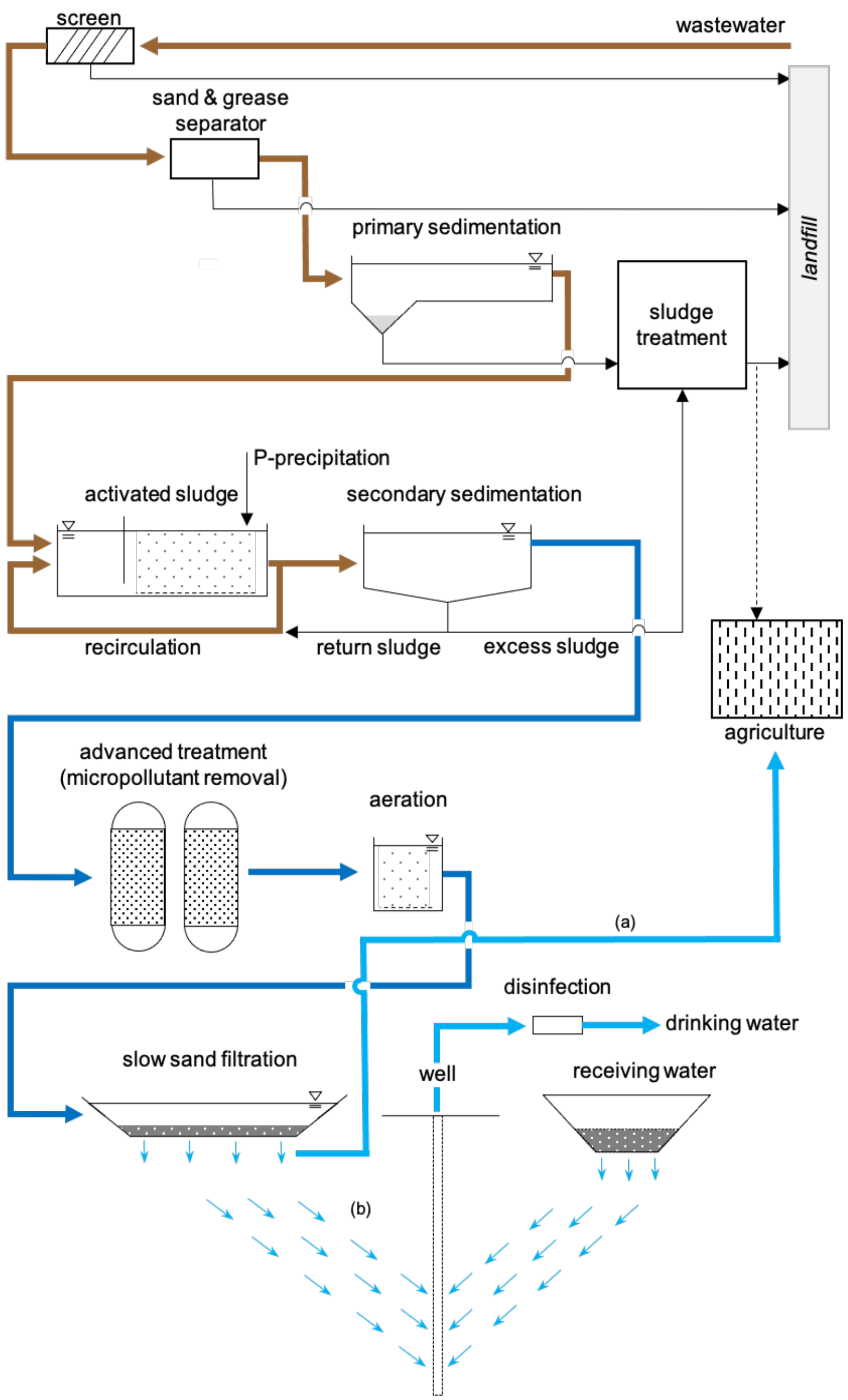
However, the selection of the design parameters is based on the low data resolution as follows:

- COD and SS is determined from the 85-percentile values based on the operating data provided by SEDAPAL,
- Nutrient parameters are based on 85-percentile values obtained from the measured data of 2 h mixed samples (ISWA); whenever applicable, the higher value was considered.

Since slight precipitation in the catchment area of the WWTP is expected, the hydraulic load is assumed to be $Q_M = Q_d/12$ at maximum inflow.

Activated Sludge Process

The activated sludge process with an upstream denitrification stage and phosphate precipitation using metal salts (e.g., aluminum(II)sulphate or iron(III)chloride) is suggested to treat the waste-water. The schematic layout of the treatment plant is shown in Figure 5.11.



» *Figure 5.11: Schematic layout of the concept proposal for WWTP José Gálvez (activated sludge process) with the re-use possibilities (a) as irrigation water in agriculture or (b) for groundwater recharge (artificial groundwater recharge).*

A screen removes coarse and floating materials from the wastewater, whereas in the following grit and fat trap, mineral solids with a high density as well as floating fat and grease are separated. The materials and the sand should be disposed of as waste in accordance with Peruvian requirements, whereby any remaining organic matter, sludge or similar should be washed off or removed. The arising washing water can be treated in the WWTP.

In the primary sedimentation tank, suspended materials are removed as primary sludge. However, this can lead to an unfavorable C:N ratio due to the predominant removal of carbon compounds, causing the need for additional carbon compounds the denitrification stage. The presumably high concentration of N-compounds in the inlet (calculated values) indicate an unfavorable C:N ratio, therefore a primary sedimentation tank should be omitted in order to keep the necessary additional C-dosage low. The designed retention time in the primary sedimentation tank is set at one hour. Accordingly, a volume of 1 080 m^3 is required. However, if necessary, a bypass around the primary sedimentation tank for e.g., wastewater with low solid concentration should be included.

The biological stage is divided into an upstream anoxic ($<<$ 1 mg/L O_2, solved, nitrate is present) denitrification tank and an aerated nitrification tank ($>$ 3,0 mg/L O_2, solved). In the denitrification tank autotrophic bacteria metabolize nitrate together with the easily degradable carbon. In the nitrification tank, nitrogen compounds (mainly ammonium) are microbiologically converted to nitrite and subsequently to nitrate. In addition, carbon compounds are decomposed. The nitrate-rich effluent from the biological stage (mixture of partially treated wastewater and activated sludge) is recirculated into the denitrification zone. The precipitation of phosphate (P-precipitation) occurs by means of iron salts (e.g., iron(III)chloride or aluminum(II)sulphate). The precipitants can be admixed to the primary sedimentation tank, the biological stage or the secondary sedimentation tank. Since the precipitant does not selectively precipitate further compounds or adsorb them on the formed flocs, the addition to the biological stage or to the inflow to the secondary sedimentation tank is preferable to admixed to the primary sedimentation tank.

In the secondary sedimentation tank the activated sludge is separated from the treated wastewater. Nevertheless, suspended solids still contained in the effluent are removed by means of a subsequent rapid sand filtration. Optionally, effluent of the rapid sand filter can be disinfected with chlorine, whereby also biomass growth in the downstream slow sand filter is reduced.

In the slow sand filter, bacteria and fine suspended solids, which have surpassed the rapid sand filter, are removed, so that the effluent wastewater is free of pathogenic microorganisms. It can either be taken (a) directly from the outlet of the slow sand filter and used for irrigation purposes or (b) for artificial groundwater recharge.

The arising sludges usually are to be treated by means of suitable processes such as anaerobic sludge digestion with gas utilization or aerobic composting. Sludge treatment can either be realized externally e.g., in a large treatment facility or on site of the WWTP (sludge treatment). Anaerobic treatment produces energy rich gas, but also ammonium containing sludge water. After treatment, the remaining stabilized sludge can be used as a fertilizer in agriculture, for example, provided that Peruvian limit values are complied with. Depending on the process selected, the dimensioning of the treatment plant would have to be supplemented by the return load from the (anaerobic) sludge treatment processes.

Based on the inflow values and the effluent values, the required treatment capacity is calculated. By means of the design according to DWA-A 131 the design data were determined as well as arising sludge masses from the activated sludge process. The return load is estimated via the nitrogen compounds removed in the primary sedimentation tank. About 10 % of the TKN-concentration in the inflow to the primary sedimentation tank is removed together with the primary sludge. After anaerobic sludge treatment, about half of this is available as ammonium nitrogen, usually returned to the activated sludge process.

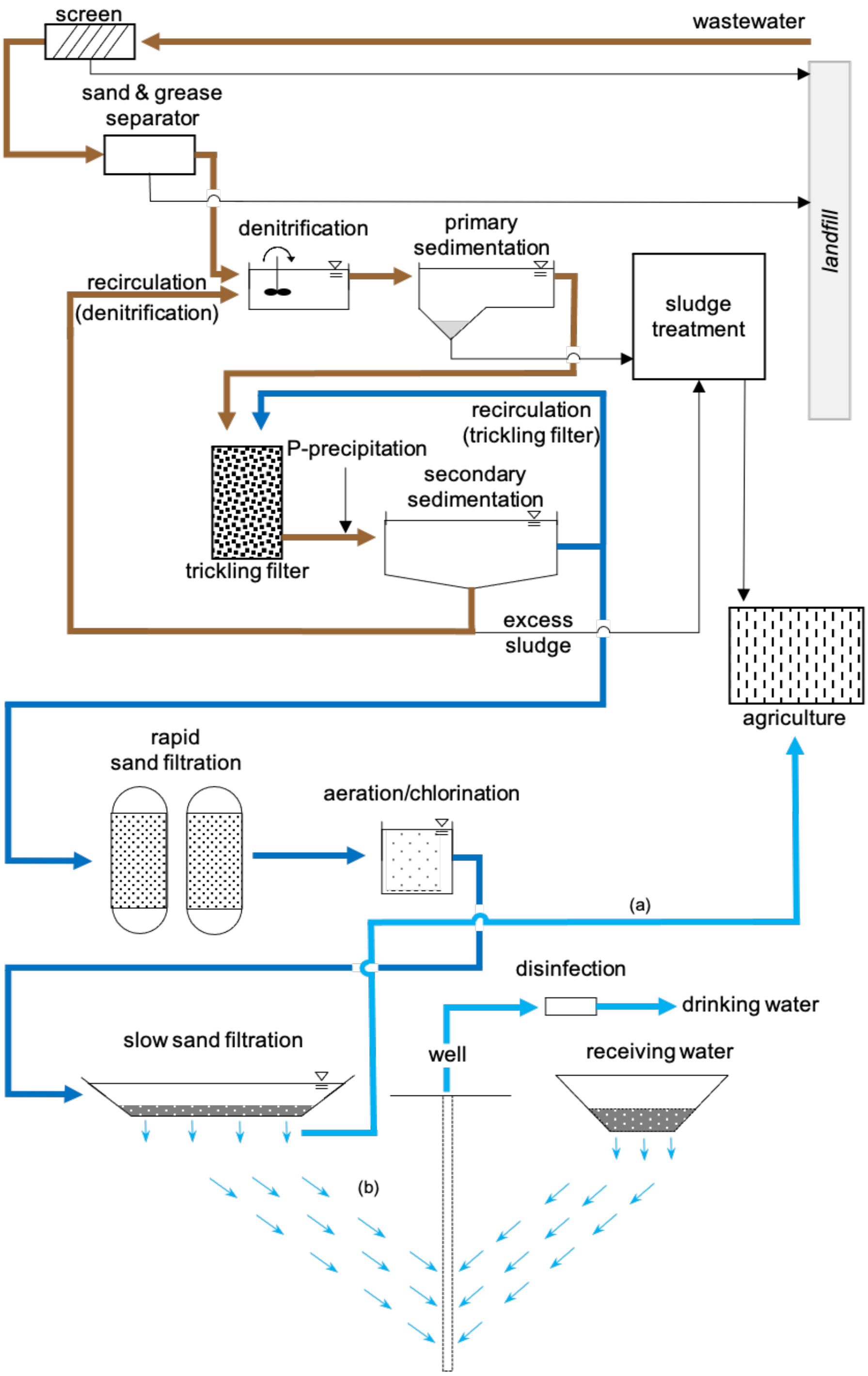
Before further use of the treated wastewater, residues of possibly existing suspended substances should be removed by means of rapid sand filtration. Before the subsequent slow sand filtration, chlorination (chlorine gas) must be provided to maintain hygienic conditions. Any disinfection byproducts such as chloramines formed have an additional disinfecting effect and can contribute to a longer service life of the subsequent slow sand filter.

The hydraulic treatment capacity of the rapid sand filter has to be dimensioned for peak loads (here: Q_M). However, since the slow sand filter has a sufficient retention volume to handle short-term hydraulic loads and a large surface area, the hydraulic design of the slow sand filter considers the daily volume flow (Q_d).

Trickling Filter Process

In the trickling filter (TF) process microorganisms are attached firmly to a surface, whereas in the activated sludge process the microorganisms are suspended. In order to enable sufficient contact of the microorganisms with wastewater and oxygen, support materials with the largest possible surface area are used on which the microorganisms can attach. In addition to lava stones, mainly plastic packing materials with a well-defined structure and surface are used.

The energy input in the trickling filter process is lower than in the activated sludge process, as no energy-intensive aeration is required. Due to the data situation with the low resolution (daily variation), the 85-percentile values were used for dimensioning. Figure 5.12 depicts the process scheme of the trickling filter treatment plant with upstream denitrification. Prior to biological treatment, the wastewater is mechanically pre-treated to remove coarse materials and sand. Subsequently, the wastewater passes together with nitrate-rich return sludge from the secondary settling tank into the denitrification stage. Heterotrophic bacteria metabolize easily degradable carbon compounds and nitrate under anoxic (no oxygen solved) conditions. This reduces the load on the trickling filter significantly. In the subsequent sedimentation tank excess sludge and suspended solids are separated and, if necessary, returned to the denitrification stage. The sludge mixture removed must be stabilized aerobically or anaerobically. The solids-free supernatant is then trickling into the trickling filter and dissolved wastewater constituents are metabolized by the sessile microorganisms. Since easily degradable carbon compounds were already metabolized in the denitrification stage, treatment volume in the trickling filter can be reduced. From the trickling filter effluent, sludge is removed in the secondary sedimentation tank and returned into the denitrification stage. Furthermore, the inflow to the trickling filter must be diluted with effluent from the secondary sedimentation tank to achieve a good effluent quality. The almost solids-free outlet of the secondary settling tank is fed to a rapid and a subsequent slow sand filter to remove residual particles and microorganisms.



» Figure 5.12: Schematic layout of the concept proposal for WWTP José Gálvez (trickling filter process) with the re-use possibilities (a) as irrigation water in agriculture or (b) for groundwater recharge.

The design data were determined by designing according to DWA-A 281 (2001). In the case of anaerobic sludge treatment, a return load of 10 % nitrogen is assumed, i.e., the nitrogen load removed by the primary sedimentation tank is returned to the treatment plant via the sludge water arising in the dewatering of digested sludge. Furthermore, recirculated nitrate is presumably denitrified. In addition, by simultaneous denitrification in the trickling filter in the heterotrophic top zone, about 30 % of the nitrogen is removed. The required trickling filter volume can be split into several individual units, e.g., into 6 trickling filter units with a volume of 3 400 m^3 each (diameter 30 m). Any maintenance and flushing work can be done individually on each of the trickling filter units within low load phases. During operation, the excess sludge from the trickling filter is returned to the denitrification stage together with the nitrate-rich recirculation stream, and subsequently removed from the sedimentation tank together with the primary sludge (here referred to as excess sludge).

The process combination of upstream denitrification and trickling filter has the disadvantage of large tank volumes as well as large trickling filter volumes being necessary due to the large return ratio. However, due to the high COD-concentration of approx. 1 400 mg/L, strong dilution is required in the feed to the trickling filter. Furthermore, carbon compounds are eliminated in the upstream denitrification, relieving the downstream trickling filter. In case of anaerobic sludge treatment, due to reject water from sludge dewatering a higher nitrogen load is fed to the trickling filter. However, due to the increased return factor/ratio and the upstream denitrification stage, more carbon compounds are removed anoxically by the nitrate respiration of the bacteria in the denitrification stage.

The further treatment of the treated wastewater (rapid sand filtration, chlorination, slow sand filtration) is conducted analogous to the processes presented in chapter 5.4.2. The dimensions of the downstream filtration can be deduced from Table 5.7.

» ***Table 5.7:*** *Dimensions of the sand filtration stage.*

	PARAMETER	ABBREV.	UNIT	
Rapid sand filter (RSF)	Specific surface feed	q_A	m/h	10
	Volume	Q_M	m^3/h	1 080
	Filter surface area	A_{SSF}	m^2	108
Slow sand filter (SSF)	Specific surface feed	qA	m/h	0,1
	Volume	Qd	m^3/h	540
	Filter surface area	A_{SSF}	m^2	5 400

5.4.4 Summary of Concepts

The main results of the concepts for wastewater treatment and artificial groundwater recharge for reuse can be summarized as follows:

- The effluent of WWTP Cieneguilla meets Peruvian discharge limits. Knowledge about safe operation of the activated sludge process is available. However, at present the hydraulic load of the WWTP Cieneguilla is lower than designed. In order to achieve a further nutrient removal from the wastewater and also to enable reuse, a redesign of the treatment process is recommended. The activated sludge process is to be retained and improved by a primary sedimentation as well as nitrogen removal is to be made possible by creating a targeted flow control.

- The WWTP José Gálvez achieved poor effluent quality, which can be ascribed to hydraulic overload. A complete revision of the treatment process is proposed to comply with Peruvian discharge limits and to allow the reuse of the effluent. Two different cleaning methods are proposed: the activated sludge process or trickling filter, both with subsequent rapid sand filtration, chlorination and slow sand filtration to further disinfect the effluent. The effluent could be used to irrigate nearby agricultural areas or for artificial groundwater recharge. Arising sludge from the treatment process (activated sludge or trickling filter) should be stabilized, e.g., by anaerobic sludge treatment. Gas produced in this process can be used for energy production in a combined heat and power station.

5.4.5 Evaluation of the Concepts with Regard to SDG 6

Hanna Kramer & Manuel Krauss

To evaluate the current situation in the lower catchment area regarding the achievement of SDG 6, the catchment area of the WWTP José Gálvez was chosen as an example. Subsequently, the potential effects of a successful implementation of the proposed concept of wastewater treatment (chapter 5.4.3) on the achievement of SDG 6 were assessed. The evaluation does not cover the type of wastewater treatment (e.g., activated sludge or trickling filter) but evaluates the effect of enhancing the wastewater treatment situation in general. The evaluation is based on census data from the year 2017 as well as documents received from SEDAPAL. A major challenge in the lower catchment area was to obtain the necessary data for the evaluation of indicators and to handle data gaps.

As boundary conditions are similar, the results of this evaluation can be transferred to effects that can be expected from the concept of retrofitting WWTP Cieneguilla (chapter 5.4.2).

Indicator 6.2.1

The proposed retrofit of the WWTP José Gálvez will not impact indicator 6.2.1, because households are already connected to the existing WWTP in José Galvez and the concept has no influence on the connection rate and the indicator does not assess the quality of treatment.

Indicator 6.3.1

Currently, as the capacity of the WWTP José Gálvez is not sufficient for the incoming wastewater loads, the effluent is still contaminated. With the implementation of the retrofit all of the incoming wastewater will be treated.

Indicator 6.3.1 evaluates not only domestic but also industrial wastewater. In the lower catchment area with more industry, it is expected that the limit values for indirect discharges are being met.

Indicator 6.3.2

The proposed groundwater infiltration will have a positive impact to avoid salt water intrusion and high nitrate values (chapter 5.2.1) in the groundwater aquifer.

Indicator 6.4.2

Although the share of groundwater is increased by the implementation of the artificial groundwater recharge, it is not increased by endogenous precipitation, thus this share cannot be counted towards the term total renewable freshwater resource (TRWR). Therefore, according to the indicator definition, the proposed concept will not affect the results of indicator 6.4.2.

Indicator 6.6.1

The proposed retrofit if the WWTP José Gálvez has no impact on spatial extent of water related ecosystems. The quality of water within these ecosystems is already assessed with indicator 6.3.2. The quantity of water contained within these ecosystems may be affected, as the quantity of groundwater within the aquifer will increase through the proposed artificial groundwater recharge with treated wastewater (chapter 5.4.3). Negative impacts resulting from the retrofit of the WWTP José Gálvez are not expected.

5.5 Interim Conclusions Lower Catchment Area

The drinking water supply for the growing population and industry in the lower Lurín valley is based on the local groundwater resources, which are additionally intensively exploited as irrigation water for agriculture.

Groundwater recharge is exclusively from the Lurín river, through natural bank filtration or artificial infiltration due to irrigation. The river water has a very high percentage of untreated or poorly treated wastewater during most of the year.

The groundwater extracted from deep wells is predominantly of very good physical-chemical and hygienic-microbiological quality. This indicates an effective cleaning of the river or infiltrating wastewater during the underground passage.

The groundwater resources in the Lurín valley are already heavily overexploited and are not able to cover the increasing demand. According to a hydrogeological report (Coronel, 2012), especially numerous shallow wells are expected to dry up in the coming years.

In the hazard analysis, several nitrate emitting hazardous events with a high risk of nitrate infiltration were identified. As a result, the nitrate concentration in extracted water from a few wells is above the recommended WHO guideline value of 50 mg/L (WHO, 2017). Especially the effluent of the WWTP José Gálvez, has been identified as a high risk for the raw water of the wells, since it is used for irrigation and fertilization, resulting in high nitrate concentrations in several groundwater wells.

A concept was developed for sustainable groundwater extraction in the lower Lurín Valley both qualitatively and quantitatively by infiltrating safely treated wastewater.

The concepts were developed for two different cases, WWTP Cieneguilla and WWTP José Gálvez, and it has been shown that they can be implemented in different process variants in both existing and new buildings. With the implementation of the concepts all of the incoming wastewater will be treated. The proposed groundwater infiltration will help to avoid salt water intrusion and high nitrate values in the groundwater aquifer. Furthermore, no negative impacts resulting from the implementation of the proposed concepts are being expected.


Picture: M. Krauss

6. Central Results and Lessons Learned

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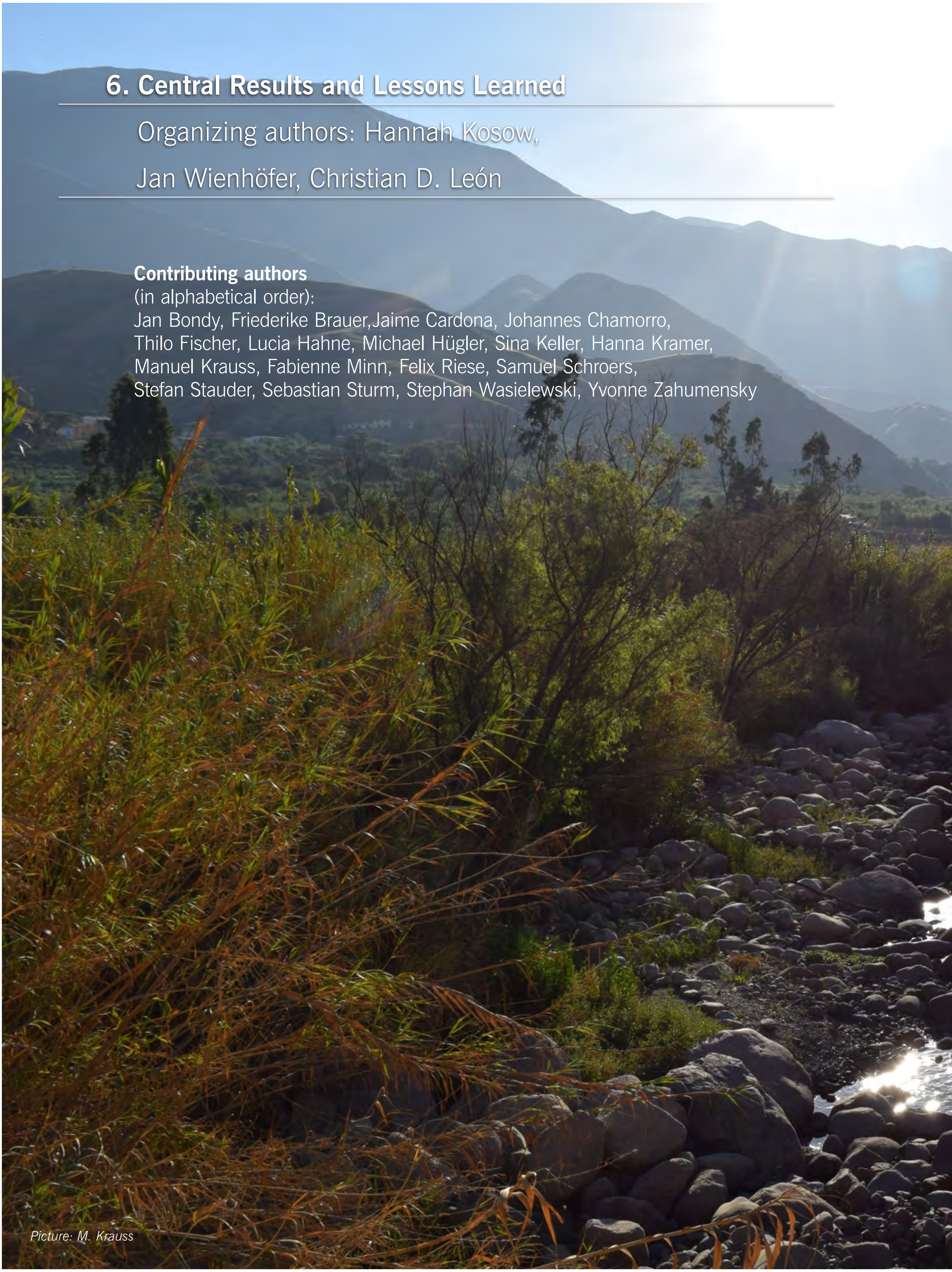

Picture: M. Krauss

In this concluding chapter we summarize and reflect our main findings. The specific approach of the TRUST project is characterized by two streams of activities: i) creating a multidisciplinary information base for the river catchment Lurín, and ii) developing integrated concepts for water use as well as for drinking and wastewater management. These two streams are interlinked and cover the bandwidth of water-related issues in the Lurín catchment ranging from water resources over water use to water management. Readers interested in our central findings and specific recommendations regarding the Lurín catchment are invited to section 6.1. Those interested in our methods, approaches and tools, find information about added value, challenges, and transferability in section 6.2. Finally, we conclude with the main general recommendations and lessons learned which we would like to share with actors from water management research and practice worldwide in section 6.3.

6.1 Central Results and Recommendations to the Lurín Catchment

What did we learn about the Río Lurín catchment? What do we recommend regarding quantity and quality of water resources (6.1.1) and regarding integrated water use and management concepts (6.1.2)? The following central results and recommendations have been validated and refined with local stakeholders during a virtual expert workshop in September 2020.

6.1.1 Water Resources and Water Quality

WATER RESOURCES

We were able to improve the estimates for the general availability of water resources in the Lurín catchment with the newly collected data. The data from the stream monitoring at Manchay set up by the TRUST project substantiated the initial assumption that the Lurín catchment offers unused water resources during the wet season (around 55 million m^3 in 2019). To make use of these resources, different measures to retain and stabilize the water flow of the Lurín River should be investigated, including techniques enhancing infiltration, or new (possibly cascading) reservoirs. Groundwater resources constitute another major part of the water extraction in the catchment, which needs to be controlled and regulated. The stream gauges at the borders of the main infiltration zone can help in specifying the sustainable withdrawal amounts. In addition, enhancing groundwater recharge from river water and water re-use can be options to help further attenuating a decline in groundwater volume. All measures require coordination of diverse actors and support by research to ensure the technical optimal design, social acceptance, and least environmental impact.

WATER QUALITY

The prevailing water quality determines the usability of the available water resources. Safeguarding the supplies by controlling and decreasing water pollution is thus an important part of water resources management. In the upper parts, the Río Lurín shows a water quality that is typical for river waters with permanent and slightly fluctuating contaminations with fecal bacteria and usually low turbidity during the dry season, while high turbidities values can be present during the rainy season. Microbial contaminations were also found in the surface water stored in reservoirs, which are used for irrigation and as drinking water source. This was expected due to the concurring use as ponds for grazing cattle.

Further downstream (near Cieneguilla), the river exhibits a high share of (partly untreated) wastewater, and thus high microbiological contamination, high nitrate and total organic carbon (TOC). In addition, numerous anthropogenic trace compounds are present. In contrast, our sampling found a very good quality of the groundwater, which implies a good filtering capacity of the soil above the aquifer. Only few wells showed elevated concentrations of nitrate, due to the infiltration of poorly treated wastewater used for irrigation, and of calcium and sulfate from geogenic sources. Anthropogenic compounds and heavy metals like uranium or vanadium were sporadically detected, but with concentrations below critical values. These conditions are generally promising for managed aquifer recharge in the lower Lurín valley with river water and treated wastewater.

Several risks were identified for water resources in the Lurín catchment. The risk for pollution is immediate when using untreated or insufficiently treated wastewater for irrigation; this also applies if untreated wastewater is discharged to the river, from which irrigation water is extracted further downstream. Drinking water reservoirs and abstraction sites need particular protection. The areas should be fenced off to keep the cattle away, and they should be clearly labeled to increase the compliance with the protection measures. To be successful, alternatives (e.g., ways of watering and feeding the animals) have to be developed together with the community and livestock owners. Private groundwater wells in the lower catchment area are not always secured sufficiently against flooding and other influences. This is a potential risk of groundwater pollution, because wells pose a direct connection between surface and groundwater by evading the protecting soil and rock layers that can act as filters.

The awareness for risks to drinking water resources was heterogeneous across the catchment's population. In addition, professional actors were not all familiar with concepts for resource protection like the WHO Water Safety Plan (WSP), although these could help to implement effective resource protection and risk management options. Capacity building is necessary to generate the technical and methodological skills, and linked to that, public communication is important to raise the awareness for water quality issues and their meaning for public health.

» ***Figure 6.1:*** *Río Lurín in the dry season (October, mid catchment part). Picture: C. D. León.*

6.1.2 Integrated Water Use and Water Management Concepts

ACTORS

To develop integrated water use and management concepts for the Lurín catchment area, understanding the actor landscape in the water sector was crucial. In sum, the actor landscape is complex and dynamic; the cooperation between old and new actors, as well as actors from the upper and lower catchment is challenging. In addition, there is a high discrepancy between formal power and effective power.

In the upper catchment area, forms of local rural self-governance play an important role in water management. The performance of key organizations like communal drinking water service providers JASS - or their municipal counterparts ATM - depend on personnel capacities, technical and financial support, as well as on political priorities, and the socio-cultural awareness of the role that water has for public health. Often, financial resources are not sufficient to make major investments in infrastructure or to implement new technical concepts. Not only the internal organizational management needs strengthening, but also sustained technical and financial support from government actors is required. It is essential to find ways to improve water services and to sustain such improved services through a combination of financial, technical, and social support, appreciation, as well as awareness rising of the population in general. To this end, it is necessary that all responsible actors collaborate closely and prioritize the common goal of a sustainable water management.

In the lower catchment area, different types of water use are administered and (should, by law, be) controlled by various different actors. Still, there are overlaps and uncertainties regarding competencies and hierarchies of regulatory bodies (ANA vs. SEDAPAL vs. municipalities). In particular, the cooperation between district municipalities and SEDAPAL is not optimal. There are highly diverse industries, of which only a small part is represented within formal multi-stakeholder platforms. The communication, exchange and cooperation of all actors, especially between actors of the upper and the lower part, should be strengthened through inter-municipal cooperation (e.g., mancomunidades) and multi-stakeholder platforms as the water council CRHCI CHIRILU, especially within the GTM Lurín. So far, activities and impacts of these platforms remain far below their potential. The multitude of well-organized social and water related NGOs in the Lurín catchment is a strong resource. These organizations should be emphatically invited to represent civil society and environmental concerns within these platforms. Furthermore, we recommend better integrating representatives of the diversity of industrial sectors, which are present in the Lurín valley, into these platforms.

WATER USE CONCEPTS AND CONFLICTS

In Lurín, there are diverse water users, namely households, industry, agriculture, green areas (e.g., for tourism), as well as water-related ecosystems. All the while the classical conflict between rural and urban realities is still relevant; water conflicts are enhanced due to an increasing demand triggered by industry and population growth. There are multiple (potential or latent) water use conflicts between water related objectives of different user groups. Important trade-offs, i.e., interactions, exist between the (favorite) policies, instruments and measures of the different user groups to reach their respective objectives. In the upper part, there is a (potential) water use conflict due to the joint use of reservoirs for both, households and agriculture (quality-issues due to contamination). In the lower catchment part, households, agriculture and industry compete over the use of groundwater (water quantity conflict). In addition, water safety is challenged by insufficient and/or unsafely treated wastewater (water quality conflict). New solutions, as improved wastewater treatment, might lead to new use conflicts: Actors need to decide whether they use the new resource, i.e., safely treated wastewater, directly for irrigation of agriculture or green area or indirectly (through artificial aquifer recharge) for drinking water supply.

The current status quo policy-mix (combination of measures) in the catchment is neither effective, nor consistent or synergetic - nor sustainable regarding the attainment of SDG targets 6.1 and 6.6. Our analysis identified alternative policy-mixes, which could allow obtaining the different objectives of the various water user groups in the entire Lurín catchment in a more optimal way. These mixes include, e.g., 'responsible (re)-use', 'measure and recharge', and 'tradition and modernity'. They are detailed in chapter 3.4. Every consistent, synergetic and sustainable future policy-mix that we identified requires safe wastewater treatment and reuse (mainly for irrigation of agriculture and green areas, but also in the industry) in the lower catchment part. However, to address (potential) new use conflicts around safely treated wastewater, the issue needs to be put timely and prominently onto the political agenda and to be discussed in open dialogues including relevant stakeholders of the Lurín catchment.

» ***Figure 6.2:*** *Irrigation of green areas in the central plaza of Lurín. Picture: C. D. León.*

WATER MANAGEMENT CONCEPTS

We developed integrated transdisciplinary drinking water and wastewater management concepts for the upper and lower catchment parts.

Safe Drinking Water Supply

The drinking water supply situation in the upper and lower parts is very heterogeneous, ranging from safely managed to basic or even unimproved. Overall, there is general awareness of hygienic issues linked to drinking water quality by the population in the Lurín valley.

In the upper catchment part, basic source protection and simple drinking water treatment methods are required (e. g., fencing off cattle from abstraction sites, coarse media or multistage filtration). Advanced treatment (e.g., membranes) will most likely be too expensive and would also pose maintenance issues (e.g., management of utilities, but also vandalism). A successful implementation of chlorination in the upper part is generally hindered due to lack of chemicals, maintenance, and management concepts (who pays, organizes and applies the chlorine). Topics like power supply, quantity-based dosage, periodically high turbidity/TSS (Total Suspended Solids), and the presence of chlorine resistant pathogens have to be considered. Presently, the local population usually boils the water used for drinking and food preparation. This boiling is necessary and efficient to avoid waterborne diseases. Furthermore, it shows that the population is aware of potential microbiological contaminations of the drinking water. Although people are aware that water quantity is limited, and water reservoirs are occasionally empty during the dry season, no water saving measures are undertaken by the local population yet (e.g., permanently flushing toilets, no quantitative water tariffs).

In the lower catchment part, the sustainable management of the Lurín aquifer must be ensured (quantitatively and qualitatively). The aquifer is heavily exploited, including for the drinking water supply of Lima. Withdrawal amounts need to be monitored and regulated so that they are not exceeding the renewal rate of the groundwater resource. Wells and wellheads have to be properly designed and protected to preserve the groundwater quality. According to the existing hydrological data and the identified quality of river and groundwater, the pre-conditions for artificial aquifer recharge in the lower Lurín valley are very promising. River water and eventually specifically treated wastewater could be used for infiltration. As groundwater resources are already overused, such measures are particularly important with regard to the increasing water demand by the population and industries.

Safe Wastewater Treatment and Reuse

Regarding wastewater, in the entire catchment, there still are many settlements without a sewage system or with a sewage system that is not connected to a wastewater treatment plant. Therefore, wastewater is often discharged untreated into water bodies.

In the upper catchment, often, there is a sewer system installed and the wastewater is collected. However the wastewater is not treated but directly discharged into the environment or even used for irrigation. To improve this situation, we propose to treat the wastewater using trickling filters, a robust and reliable technique. For very small settlements (anexos), systems with source separation are proposed. In these, feces, urine are collected and treated separately from slightly contaminated greywater from the kitchen and bathroom. Feces and urine can be used as fertilizer after sanitization. Regarding irrigation, today, significant quantities of irrigation water stem from reservoirs. Treated wastewater can contribute to irrigation, especially during the dry season or when reservoirs are empty. If use of treated wastewater for irrigation is not required, the treated wastewater can be safely discharged into the water body. However, to safely treat wastewater in rural areas, the influence of commercial activities (slaughterhouses, etc.) on the composition of the wastewater must be considered.

In the lower catchment, existing wastewater treatment plants do not necessarily work properly. Also, knowledge about a trouble-free operation of a wastewater treatment plant often is not sufficiently available - or limited to single persons. Reuse of wastewater is already occurring today in the lower catchment but mainly indirectly. The effluent from treatment plants is at times completely reused for irrigation purposes. And, during the dry season, river water of the Lurín is composed solely of wastewater and is directly channeled into irrigation channels. This means, reuse is already being implemented informally, but the quality of the water does not meet official requirements for irrigation water. Adequately treated wastewater could improve this situation and lead to safe water reuse, mainly as service water for industrial processes or irrigation water in agriculture.

Overall, we found that from a purely technological standpoint, there are straightforward, not to say simple, ways to implement safe drinking water supply and water reuse. However, local boundary conditions such as hydrological, social, and administrative conditions as well as local water management have to be considered. The possibility to tailor water management concepts to local contexts is key for implementing these solutions. Furthermore, political will and political priority need to be given not only to drinking water supply but also to wastewater treatment issues. Then, local stakeholders need to be deeply involved into the development of concepts, implementation and use of (technical and organizational) solutions. In addition, the planning and operation of drinking water and sewage plants can be challenging in rural areas as well as in urban areas of the Lurín, when capacities and monitoring data on water quantities and qualities are lacking (6.1.1).

In sum, we have obtained a multitude of results directly relevant for improving an integrated water management of the Lurín catchment. Only some of our results can be generalized directly beyond our study area. But many of our methods, approaches and tools are applicable in other regions facing water scarcity – when tailored to the specific local contexts of their application. How to do so will be discussed in the following section.

» ***Figure 6.3:*** *Field visit to the wastewater treatment plant Cieneguilla. Picture: C. D. León.*

CAPACITY BUILDING

Capacity development plays a decisive role in achieving the Sustainable Development Goals (SDG) related to clean water and sanitation. To contribute to water-related capacity building and visualize and transfer the methods and planning tools developed by the TRUST project, we have organized and implemented various capacity building activities.

We developed a multi-level capacity-building program for key stakeholders in the Peruvian water sector, like professionals from water utilities, students from universities, and local water and sanitation operators. This program included a Master Class organized by decon international with lectures and seminars on tools to strengthen future decision-making and water safety planning processes, delivered by the TRUST project partners Disy, ISWA, KIT-IWG, TZW, and ZIRIUS. Close cooperation with and direct involvement of the Peruvian Water Competence Center (CCA), the provider of water and sanitation services in Lima (SEDAPAL), and the National Agrarian University (UNALM) ensured the sustainability of disseminated results. Capacity building included the identification of professional training needs, design of modules and preparation of materials, and the implementation of training courses. Based on participants' interactions during the trainings, a strong need for improvement of asset management programs of water and wastewater companies became obvious. Using open-source platforms for geo-digitalization and mapping of network infrastructure was considered as relevant. Participants realized the potential of using open source software and existing online courses to increase their use of monitoring and control programs. Discussions stressed water companies' importance in the continuous improvement of drinking water supply and wastewater disposal. Likewise, several challenges and critical points in the sector were stated and debated, e.g., solutions for periods of drought, the use of treated wastewater for irrigation and industrial processes, efficient technologies for the country's needs, water and risk management, and increased information and transparency of water quality.

» ***Figure 6.4:*** *Capacity Building Master Class at the Expoagua Peru 2019. Picture: C. D. León.*

KIT-IPF researchers hosted a 2-day workshop in 2019 about the combination of artificial intelligence and remote sensing at the Universidad Nacional Agraria La Molina (UNALM) in Lima, Peru. Participants learned about machine learning fundamentals, artificial intelligence, remote sensing techniques, and applied machine learning approaches on satellite and reference data during hands-on sessions. Materials, methods, and datasets are freely available, and the code for the workshop can be accessed online. One example of such as freely available code is provided by Leitloff and Riese (2018), focusing on the handling of Sentinel-2 satellite data.

ISWA and TZW organized a one-week training workshop for 24 employees of SEDAPAL in 2019. The main topics were groundwater and river water quality in the Lurín valley, optimization measures for the existing wastewater treatment plants, and artificial aquifer recharge - state of the art in Germany. A visit to the wastewater treatment plants in Cieneguilla and San Bartolo was also included. During the workshop, the possibilities for water reuse by advanced wastewater treatment and artificial aquifer recharge in the Lurín valley and other regions of the arid coast in Peru were intensively discussed.

KIT-IWG was closely involved with teaching at UNALM by taking responsibility for an advanced seminar, in which students discussed current research papers and developed research approaches for their final year projects in the field of hydrology and water resources. In cooperation with SEDAPAL and SENAMHI, KIT-IWG organized field trips of several days‘ duration to inspect existing and potential future hydrological monitoring sites in each of the catchments Lurín, Chillón and Rímac.

In sum, our activities revealed an important need and interest by local actors for capacity building. Ensuring a continuous and sustainable access of relevant stakeholders to the knowledge base established by TRUST project is crucial in order to improve and ensure the local use of the proposed planning tools for integrated water resources management.

6.2 Added Value, Challenges and Transfer of TRUST Approaches

Which approaches, methods and tools – established ones and those newly developed within the TRUST project – were useful to come to results? In the following, we report on the added value, challenges as well as on conditions of transfer of approaches for generating a sound multidisciplinary data base (6.2.1) and for developing integrated water use and water management concepts (6.2.2). These insights are addressed in particular to those readers, who are interested in transferring our approaches to their specific issues and contexts, as e.g., (applied) researchers from natural, social and engineering sciences, consultants as well as administrations.

6.2.1 Approaches for Generating a Sound Multidisciplinary Information Base

MONITORING WATER QUANTITY AND QUALITY

Water resources planning can only be successful on the basis of comprehensive, representative, and accessible information. Limited availability of data is a frequent concern in all kinds of water-related research and management – and it was a concern in the TRUST project, too. We dealt with it through the collection of existing data from available sources, their systematic consolidation, and strategic acquisition of new data (chapter 2).

While the possibilities for continuous monitoring of water quantity and water quality certainly depend on available funding, important insights on water quantity can already be generated with a small number of stations at the right locations. This was shown by the example of new stream gauge at Manchay in addition to the existing gauge at Antapucro. Of high importance are also the ongoing maintenance of stations and continuous reference measurements to increase the reliability of rating curves and thus decrease the uncertainty of the discharge estimates. Establishing and maintaining a monitoring network for water quantity is a challenging task in remote and mountainous areas, which certainly requires long-term efforts and commitment. Long time series with 30 years or more are even more important, if also trends in connection with climate change or land use change are to be considered in management decisions. As hydrological models require data for setup, calibration and validation, the quality of the data base also determines the quality of the model predictions.

Evaluating water quality and associated risks still requires conventional lab analyses, both physical-chemical and microbiological. Getting reliable water quality data from remote sensing is currently not possible, and installing sensors for telemetric data is unfavorable due to a possible loss of expensive equipment because of flooding or vandalism. Test kits that allow simple water analyses to be carried out by specifically trained local actors can provide an additional means to acquire water quality data. Measuring instruments can be operated locally, local competencies are strengthened sustainably. These should be made more widely available. For lab analyses, qualified sampling and analytical procedures are essential, which requires well-trained staff, too.

REMOTE SENSING

Remote sensing techniques are increasingly promoted as an alternative way to gain information about physical parameters such as soil type, soil moisture, or land cover and land use. It has been demonstrated in recent years that machine learning approaches can successfully link recorded remote sensing data and reference data about the target parameter. Successful applications are, for example, the classification of land use, the detection of land cover changes, and the estimation of soil moisture. However, the use of machine learning approaches in estimating physical parameters is a challenging task. This task is tackled (Riese & Keller, 2020), but not entirely solved. First, sufficient reference data describing the physical target parameter are needed to train machine learning approaches. Second, the upscaling from a small-scale area to a satellite scale is extremely challenging and requires specific measurement principles such as UAV-recorded data and adequate reference data. Such data are laborious to obtain. To predict physical parameters in a real-world area, much data need to be measured over a long time. When relying on existing data such as maps, the reference data can lack the necessary precision, since they contain already regionalized data that are not necessarily accurate. Transferring training results to other areas has also proven to be difficult, as the remote sensing signatures are often specific for a particular study site. Land use classes that are most relevant for risk management, like agriculture, urban areas, and settlements, need to be included in the reference data (balanced datasets), otherwise these classes cannot properly be detected with machine learning approaches. Overall, the remote sensing research part in the TRUST project has provided a basis for methodological solutions by establishing a land cover change detection approach with deep learning on multi-temporal satellite data (Sefrin et al., 2021) and an analysis of sequential satellite images with extended LSTM architectures. Further, a new dataset has been acquired. The freely available "Aerial Peruvian Andes Campaign" (ALPACA) dataset contains hyperspectral UAV data and soil moisture values of several test sites in Peru (Riese et al., 2020).

STAKEHOLDER ANALYSIS

Governance issues and conflict analysis require social science data and information. Mapping of stakeholders is important to obtain an overview on roles and relations. It may require frequent updates to depict the dynamics of actor constellations, and to identify developments over time. Stakeholder analysis allowed our project to identify whom to involve during what project activity and in what intensity (informing, consulting, and collaborating).

Obtaining information about actor constellations can be very complex. The understanding of contexts may remain incomplete when only obtaining data from a distance through internet research. Therefore, repeated field trips and interviews with key actors are required to achieve a full understanding and detailed overview of the position of stakeholders in relation to the project goal, and of the interrelations between stakeholder groups. To gain a comprehensive picture of actor constellations, we recommend comparing externally elaborated stakeholder landscapes with the internal view of local stakeholders themselves.

Stakeholder analysis is a well-established methodology when starting joint projects and conducting participatory processes. An active involvement of key actors is important, while other stakeholders should be regularly informed about results, experiences, and decisions during the project. Stakeholders who are sceptical about the project goals should be given the same attention as others. This allows all actors involved, i.e., analysts and local actors, to better understand critique and opposition. This is a precondition to consider all positions when taking decisions and planning processes. Knowing about and respecting justified critical arguments can contribute to locally acceptable solutions.

CENTRAL DATA MANAGEMENT

Central data management is essential to make the available data accessible for the users. In TRUST, we set up an online application with Web-GIS for accessing geodata. This ensured that every project partner had an overview of the existing, current data. The data was prepared in tables, graphics and maps, so it could be explored interactively, and the data could be downloaded in common formats. While having a strategy for data management is indispensable for any project, implementing a specialized software environment is a relatively large infrastructure effort, which is rather worthwhile for larger projects. The efforts related to entering data, and especially the relevant metadata, should not be neglected. To be effective, the data base needs to be quality-checked, and updated regularly.

6.2.2 Approaches for Developing Integrated Water Use and Management Concepts

COMBINING THE LOCAL AND THE RIVER BASIN SCALE

Overall, our general approach combined local analysis and concepts with the river basin scale perspective. The local perspective fostered high participation and identification of local actors with the project, as well as increased local data availability and information exchange and learning processes among local actors. At the same time, it required local measurements. Missing and imprecise data were a challenge as well as missing personal continuity of decision making bodies (e.g., changing staff). The river basin perspective revealed the interconnections as well as degrees of independence/ freedom between upper and lower catchment part, but was challenged by missing data and limited data transparency.

INTER- AND TRANSDISCIPLINARITY

The interdisciplinary approach of the TRUST project led to a joint and more comprehensive problem understanding and to new insights. We recommend to others assuring an interdisciplinary approach by integrating engineering, natural science, social science, and economics, too.

Our transdisciplinary approach integrated local competences and interests into the project. To assure successful cooperation, it revealed useful to establish formal cooperation agreements (contracts). Multi-stakeholder participation, cooperation and integration revealed the different perceptions of problems and potential solutions as well as mutual expectations among different actors. It also allowed actors to develop (new) networks and alliances to pursue common strategies and overcome presumed barriers between organizations. For more detail, see also the subsection on INTEGRATED SOCIO-TECHNICAL CONCEPTS FOR SAFE DRINKING WATER SUPPLY AND WASTEWATER REUSE below.

Still, it was challenging to:

- deal with heterogeneous types and degrees of knowledge, financial and personal resources, expertise, and formalization;
- integrate multiple perspectives as well as multiple world views;
- establish and institutionalize communication between complex and fragmented actor constellations;
- link science and research meaningfully with strategy building, planning and decision-making processes of the local practice.

We strongly recommend to plan and apply sufficient resources (in particular time) for inter- and transdisciplinary integration processes to develop. Regular communication (talking and listening) are crucial to build mutual understanding and, eventually, trust. At this aim, being present on site regularly has proved being decisive. Finally, we strongly recommend to openly addressing mutual expectations and roles to foster optimal cooperation between research and practice.

» ***Figure 6.5:*** *Reservoir "Cancasica" in San Andrés de Tupicocha. Picture: C. D. León.*

SUSTAINABLE DEVELOPMENT GOAL SDG 6 TARGETS AND INDICATORS

Using SDG 6 as a point of reference assured that our results are linkable to international debates and standards through the comparability of indicators. We used SDG 6 indicators a) at the local and sub-catchment level and b) to assess the (anticipated) contribution of new management concepts. We also used SDG 6 targets as qualitative criteria for an ex-ante evaluation of policy-mixes.

Due to the specific nature of SDG 6 and the associated global demand for data sources to assess the goal achievement, new data are being collected, and existing data sources are adapted to enable this assessment. In Peru, national census data from 2017 contain far more relevant information for the assessment of SDG 6.1 and 6.2 than census data from the year 2007 and thus was a helpful data source that was ready to use. At the same time, indicators and locally surveyed data do not always match well. Beyond census data, lacking data availability remains a major challenge. Reasons for the data gap are too little technical capacity, too few resources, lack of monitoring structures and data management systems (Harlin et al., 2020). We recommend checking the plausibility of publicly available data and to triangulate it with your own data. Own data can be gained through on site data gathering as well as through validation with the help of local actors and population. A combined natural-social science approach was beneficial, especial in areas where no or few reliable data are available.

Additionally, to fully monitor the achievement of SDG 6, indicators would be required that cover aspects addressed by SDG targets in a more comprehensive way: When looking at the SDG 6 indicators, some aspects specified in the target are not covered by the indicators yet. For example, target 6.2 points out to pay special attention to women and girls and those in vulnerable situations. However, indicator 6.2.1 omits this aspect (Guppy et al., 2019). Thus, additional data disaggregated by gender as well as gender-specific indicators would be required. Access to water and sanitation has different direct impacts on women and men regarding health, education, employment, income, and empowerment (UNDESA, 2014). Furthermore, there are weaknesses in the formulation of targets and indicators regarding some essential elements of the human right to water and sanitation, such as affordability and acceptability.

WSP TOOL FOR HAZARD ANALYSIS AND RISK MANAGEMENT

The WSP-Tool has been newly developed by the TRUST project. It is a decision support system that helps to increase and guarantee the security of water supply and promotes the precautionary and sustainable protection of water resources. Its structure is based on the WHO Water Safety Plan concept (WSP). It enables the recording and evaluation of risks in the catchment area and the documentation of measures for risk control. As an online application with Web-GIS geodata processing, it is usable for users without own GIS access. Data changes and updates by the users are possible with little effort. It allows joint project processing by different users, as e.g., departments, due to central data storage. That avoids redundant data management. Due to automated calculations it reduces sources of error. Still, the TRUST project results in a prototype only. This means that not all desirable functionalities are implemented and it is not ready-to-use for end users yet. Principally, the tool can be used by water suppliers or authorities for all kinds of water supply systems. Still, applying online-tools in regions with limited access to the internet is restricted.

Using the WSP tool for hazard analysis and risk management with local stakeholders facilitates harnessing local knowledge and including it in the water safety plan process. The tool offers the possibility to visualize results quickly. Thus, it supports the communication about the aims of risk analysis and helps to achieve a common understanding of which information is relevant. This can be challenging as has been shown by experience, also beyond Lurín.

The maps generated by the WSP-tool show directly where measures for risk reduction need to be implemented to increase water safety. Hence, they can also be helpful in communicating the need for risk control measures and helps to increase their acceptance and support. Applying the tool in the drinking water catchment area of Tupicocha confirmed that it is most important to take measures near the water intake at the reservoir and in the vicinity of the springs used for private water supply.

POLICY- AND CONFLICT ANALYSIS

The policy- and conflict analysis newly developed by the TRUST project allowed identifying central (latent) water use related conflicts and also developing and assessing new integrated policy-solutions for an improved and sustainable water management for the entire Lurín valley. The methodology is a generalizable form of conceptual policy-interaction modeling based on qualitative systems analysis. In our application, it made diverging goals and policy alternatives of different water user groups explicit. It revealed non-intended side-effects of policies (i.e., instruments and measures) on the effectiveness of other policies. And it allowed identifying consistent, synergetic and sustainable policy mixes for an improved water resource management of the entire Lurín catchment.

Still, the approach is an analytical tool with very low granularity. This means, it requires to assume exclusivity of alternative policies ("user A opts for policy x all over the considered catchment part" – whereas in reality, user A might apply policy x in 60 % of the catchment part, policy y in 35 % and policy z in a few very local applications). Furthermore, the approach itself does not resolve distributional conflicts such as: What user groups take over the burden to adapt their policies, and who maintains the status quo policy? How could new policy mixes be implemented and financed?

While the methodology developed here was specifically tailored to the river catchment scale, it seems applicable to other scales and to other conflictive environmental policy issues, especially inter-sectoral or nexus issues. Precondition to its application are situations with multiple and interrelated objectives and with policy alternatives compared to the status quo. More concretely, it requires assessments on policy interactions by experts and/ or stakeholders. Finally, it seems applicable to analyze interrelations between multiple SDG targets, and policies to reach these, too.

» ***Figure 6.6:*** *Stakeholder workshop in Lurín. Picture: C. D. León*

INTEGRATED SOCIO-TECHNICAL CONCEPTS FOR SAFE DRINKING WATER SUPPLY AND WASTEWATER REUSE

The TRUST project has developed integrated concepts for safe drinking water, wastewater disposal and safe wastewater reuse through inter- and transdisciplinary processes. Scientists, water and sanitation engineers, social scientists as well as local actors and stakeholders closely collaborated to develop solutions tailored to specific local situations. The integrated planning process has led to a better understanding of the issues involved among researchers and local actors. The cooperation of multiple disciplines has proven to be very helpful. Partners could benefit from the enriched perspective and also act as „door openers“ for each other. And, most importantly a target-oriented and sustainable use of water was enabled or improved.

Participatory technology assessment workshops allowed identifying evaluation criteria, which are relevant for local stakeholders. These were taken into account in the further development of the concepts. Such workshops can result in long lists of criteria that require further ranking and rating procedures. It was beneficial to carry out workshops with separate stakeholder groups to learn about their specific perspectives (e.g., actors from the upper and lower catchment). Bringing these actors together in joint multi-stakeholder workshops leads to more dialogue and fosters cooperation between catchment parts. Overall, the integrated approach allowed taking the social-embeddedness of technological concepts into account and to co-construct concepts together with local stakeholders.

Still, the integrated processes were challenged by limited data quality, which at times hindered informed decision making. Different data sources such as statistical data (from INEI), data from local project partners and own data (e.g., from a transect walk) should be employed and cross-checked (triangulated). Reporting from inhabitants can be used to check the plausibility of (publicly) available data. Site inspection (e.g., of water supply infrastructure, wastewater treatment plants etc.) has proven to be very important in order to check the plausibility of data from other sources and to put them into context (e.g., what are the effective water uses? Where is wastewater discharged to?). Furthermore, involving stakeholders with different perspectives still requires ensuring the same level of information and knowledge. And regularly, stakeholders need to be enabled and empowered to participate in the integrated planning processes – at this aim, capacity building workshops were helpful. Establishing new forms of multi-stakeholder involvement can be hindered by established formal governance structures. For established actors, incentives to include new actors are rather weak, also in early phases of planning processes. Finally, implementing concepts remains a challenge, especially beyond the status of demonstrator and pilot projects. Implementation requires political will and decision, communal support and consent for long term operation, financial support, and financial sustainability.

Central conditions to transfer our integrated concept development approach are active stakeholders; continuous and/ or repeated collaboration between local actors, researchers, NGOs; sufficient data; problem awareness; as well as comparable boundary conditions (regarding, e.g., hydrology, geochemistry, sociology, culture, education, urban water management, etc.). Local contexts, however, can be very specific, so approaches need to be carefully contextualized.

CAPACITY BUILDING

Developing and implementing capacity building programs together with local partners helped strengthen future decision-making and water resource planning processes and enable knowledge transfer for the country's water sector. Often, there is a gap between the educational background of project experts and participants of capacity building measures. This may limit the understanding of certain concepts and the use of the developed methodologies and instruments through just one or two training sessions.

Master Class lectures and seminars provide access to diverse water sector professionals and interested groups with different perspectives on integrated water resources management. They allow interdisciplinary discussions enriched by different viewpoints of each specialist and to identify academic barriers that may limit the integration of the knowledge presented to the audience. Given the limited time and breadth of topics and audience, the content and time of the master classes may be short compared to complete online or university courses. This can lead to generalization and leave participants' questions unanswered.

University workshops and seminars allowed disseminating TRUST approaches and results to Peruvian students, who will be the next generation of water experts and decision makers. This format allowed for detailed exchange and discussion, and also fostered international networking between university researchers.

The one-week training workshop with employees of the water services provider of Lima served to closely interlink research and local practice and bridge the implementation gap. The training had a strong agenda setting function within the water company. It assured the local relevance of the TRUST wastewater treatment and reuse concepts developed for the lower Lurín catchment, and their link to the strategic planning of a local key stakeholder.

Overall, the commitment by project partners as well as by local partners participating in capacity building is of vital importance to assure sustainable knowledge transfer. Major capacity building outcomes often do not become evident in the short term but become tangible overtime only.

6.3 General Recommendations and Lessons Learned

The following 20 key recommendations summarize our experiences in the TRUST project. They are addressed to actors involved in water management in prosperous water scarce regions all over Latin America and the world. We are convinced that actors from authorities and companies, from civil society organizations, NGOs as well as from international development organizations and (applied) research can benefit from these in order to achieve SDG 6.

UNDERSTANDING AND PROTECTING WATER RESOURCES (SDG 6.3 and 6.6)

1. Generate a comprehensive and reliable database for informed decision making of relevant stakeholders. A combined approach of natural science and social science for data collection is helpful, especially in regions where no or little reliable data are available. Check the plausibility of publicly available data sets by triangulation with own on-site surveys and with assessments of the local population.

2. Operate and continuously maintain monitoring stations for rainfall and discharge to enable quantification of available water resources. Carefully chose the location of new stations in regions of particular interest, for example to monitor water resources in representative locations, or to support planned measures. Then coordinate between all actors involved in hydrometeorological monitoring design and operation of the measurement network.

3. Implement a continuous water quality monitoring program for physical-chemical and microbiological parameters: For laboratory analyses, qualified sampling and analysis procedures are essential. In addition, provide local actors with analysis equipment and enable them to perform basic water analysis, like, e.g., assessing fecal indicator bacteria. Provide technical and methodological capacity building to both, central laboratories and local actors.

4. Support the assessment of land use and water quality by remote sensing techniques. Conventional field methods on the ground, however, are still necessary to enable use of the data for in-depth analysis, e.g., for risk assessments using Water Safety Plans.

5. Raise awareness for water resource protection and health risks associated with water quality. Communicate monitoring results transparently – and go beyond mere information by implementing an active dialogue and participatory processes with the local population. This provides the base to a successful implementation of risk reduction measures.

TRANSFORMING CONFLICTS THROUGH JOINT WATER USE PLANNING (SDG 6.5)

6. Implement joint water use planning to prevent and to solve conflicts between objectives of different water users and between their policies. Joint water use planning needs communication, exchange and cooperation of actors from all sectors and scales, especially between actors of rural and urban areas as well as between upstream and downstream riparian. Towards this aim, various water user groups throughout a catchment need to meet regularly and to jointly develop and implement integrated water use strategies. This could strengthen traditional forms of water governance, as rural self-administration, by embedding them into broader networks and empower new forms of water governance as e.g., catchment wide water councils.

7. Coordinate the diverse actors from the entire catchment area to ensure the optimal technical design, social acceptance, and least environmental impact of water policies. This holds true especially when implementing measures to retain and stabilize the water flow of rivers.

TAILORING WATER MANAGEMENT SOLUTIONS LOCALLY (SDG 6.1, 6.2 and 6.b)

8. Improve water and sanitation services, and the access to them. Maintain these improved services through a combination of financial, technical, political, and social support. Develop appropriate operator models and financing instruments to achieve SDGs in rural areas. Therefore, empower communal self-organizations through technical and financial support by the state as well as through information and capacity building. In addition, where tariff-based financing of water services is limited, e.g., due to a high poverty rate, implement other solutions to finance operations and to generate incentives for saving water.

9. In rural and urban areas, consider integrated solutions for drinking water supply, wastewater treatment, sewage sludge disposal, safe wastewater reuse and hygiene.

10. Adapt design, operation and maintenance of drinking water and wastewater treatment plants to local conditions.

11. Develop locally tailored solutions together with local actors: include local stakeholders, and in particular key actors, in the assessment of concepts for the treatment of drinking water and wastewater, as well as in the planning and implementation of innovative solutions (technical and organizational). Water management concepts cannot succeed without social acceptance, local support and the possibility of adaptation to the local conditions and resources of the respective operator and public authorities.

IMPROVING WASTEWATER TREATMENT AND REUSE (SDG 6.3 and 6.4)

12. Give more attention to safely treated wastewater from municipal wastewater treatment as an additional water resource in water scarce regions. There is a significant potential for reuse of this water as service water for industrial processes or irrigation water in agriculture and green areas.

13. Treat municipal wastewaters accordingly for a safe reuse. In addition, legislative frameworks and limit values for the reuse of water should be discussed and, if necessary, adapted.

14. Transform informal use of untreated wastewater for irrigation in agriculture into formalized reuse of safely treated wastewater. Direct reuse is already often taking place, although it is doubtful that the water has the required quality for irrigation. Implementing safe reuse for irrigation locally needs to be supported by capacity building und awareness rising. Furthermore, stimulate cooperation between wastewater providers and demanders (farmers, municipalities, industries).

15. Consider artificial aquifer recharge to mitigate the depletion of groundwater resources and ensure sustainable groundwater extraction. Sufficiently treated wastewater from municipal wastewater treatment plants could be used for infiltration, e.g., via artificial infiltration basins or directly in the riverbed during the dry season.

16. Put the issue of safe reuse prominently onto the political agenda and discuss it in public dialogues. This is essential to address social and cultural acceptability of reuse as well as to prevent (potential or apparent) use conflicts.

PLANNING AND OPERATING WATER AND WASTEWATER FACILITIES (SDG 6.1 and 6.3)

17. Chose technologies with low operating costs. Adapted, nature based and low-tech solutions are required to treat drinking water, especially for communities in the upper catchment areas (e.g., slow sand or multi-stage filtration). Advanced treatment (e.g., membranes) will probably be too expensive and will cause maintenance problems (service management, but also vandalism, etc.). Wastewater treatment plants must be based on a technology that allows constant treatment performance with low operating costs (e.g., using trickling filter technology).

18. Planning and operation of drinking water treatment requires the analysis of the raw water, with regard to quality aspects (e.g., presence/absence and dimension of fecal indicators and pathogen, turbidity changes and load) as well as quantity aspects.

19. Planning and operation of wastewater treatment plants require detailed data, e.g., incoming wastewater needs to be analyzed not only for COD but also for nutrients such as nitrogen and phosphorus compounds to prevent nutrient deficiencies in the biological treatment stage. Consider special emission sources, e.g., from industrial plants or other commercial activities. Detailed monitoring of wastewater treatment plants at short and regular intervals allows more stable operation and better process control

20. Pilots and demonstration plants can play an important role in visualizing and comprehending the successful use and application of treatment technologies and contribute to their acceptance. They can increase the interest and ensure reliable commitment of involved actors which are the basis for successful cooperation. Finally, these plants are useful for gathering design parameters for full-scale plants.


Picture: F. M. Riese

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Abbreviations

Abbreviation	Description
AAA	Autoridad Administrativa del Agua (Administrative Water Authority of Peru)
AAR	Artificial Aquifer Recharge
ADESAMA	Asociación en Defensa de la Salud y Medio Ambiente (Peruvian NGO)
AGRO RURAL	Programa de Desarrollo Productivo Agrario Rural (Program of the Peruvian Ministry of Agriculture for Rural Agricultural Development)
AGUA-C	Asociación Civil para la Gestión del Agua en Cuencas (Peruvian NGO)
ALA CHIRILU	Administración Local de Agua Chillón Rímac Lurín (Local Water Authority of the Chillón-Rímac-Lurín river catchments in Peru)
ANA	Autoridad Nacional del Agua (National Water Authority of Peru)
Aquafondo	El Fondo de Agua para Lima (Peruvian NGO)
asl	above sea level
ATM	Área Técnica Municipal para la gestión de los servicios de agua y saneamiento (Municipal Technical Area for the management of water and sanitation services in Peru)
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research, Germany)
BOD	Biological Oxygen Demand
BP	Breakpoint
CC	Comunidad Campesina (Peasant Community in Peru)
CCA	Centro de Competencias del Agua (Water Competence Center Peru)
CFU	Colony Forming Unit
CHIRILU	Chillón, Rímac, Lurín
CHIRPS	Climate Hazards Group Infrared Precipitation
CI	Cross Impact
CIB	Cross Impact Balance Analysis
COD	Chemical Oxygen Demand
COPDES	Conciencia para el Desarrollo Sustentable (Peruvian NGO)
CR	Comité de Regantes (irrigation committee in Peru)
CRHCI CHIRILU	Consejo de Recursos Hídricos de Cuenca Interregional Chillón Rímac Lurín (Water Resources Council of the Interregional Catchment CHIRILU in Peru)
Decon	decon international GmbH
Defensoría del Pueblo	Office of public defender (Peruvian ombudsman)
DEM	Digital Elevation Model
DEU	Deutschland (Germany)
DIGESA	Dirección General de Salud Ambiental (Peruvian General Directorate for Environmental Health)
DIRESA	Dirección Regional de Salud (Regional Directorate for Environmental Health of the government of Lima Region, Peru)
Disy	Disy Informationssysteme GmbH
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DN	nominal diameter in mm
DOC	Dissolved Organic Carbon
DW	Dugwell
ECA	Estándares de Calidad Ambiental (Environmental Quality Standards of Perú)
ECOSOC	United Nations Economic and Social Council
EDTA	Ethylendiamintetraacetate
ENEL	Enel Perú S.A.C. (Peruvian electricity company)

Abbreviations

Abbreviation	Description
ENSO	El Niño Southern Oscillation
ESA	European Space Agency
ETp	Potential Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
Fenix	Fenix Power Perú S.A. (Peruvian company)
FREDELU	Frente de Defensa Lurín (Peruvian NGO)
GEMI	Global Environmental Management Initiative
GeoSN	Staatsbetrieb Geobasisinformation und Vermessung Sachsen (Geodetic survey of Saxony, Germany)
GIS	Geographic Information System
GLAAS	Global Analysis and Assessment of Sanitation and Drinking- Water
GORE Lima	Gobierno Regional de Lima (Government of Lima Region)
GRoW	Globale Ressource Wasser (BMBF funding measure “Water as a Global Resource”)
Grupo GEA	Grupo Emprendedores Ambientales (Peruvian NGO)
GTM Lurín	Grupo de Trabajo Multisectorial de la Cuenca del Río Lurín (Multisectoral Working Group for the Lurin River Catchment in Peru)
HPC	Heterotrophic Plate Counts
IDMA	Instituto de Desarrollo y Medio Ambiente (Peruvian NGO)
INEI	Instituto Nacional de Estadística e Informática (National Agency for Statistics and Informatics for Peru) INGEM-
MET	Instituto Geológico Minero y Metalúrgico (Geological, Mining and Metallurgical Institute of the Peruvian Ministry for Energy and Mining)
IPF	Institute of Photogrammetry and Remote Sensing
Ipp	Ingenieurbüro Pabsch & Partner Ingenieurgesellschaft mbH
IPROGA	Instituto de Promoción para la Gestión del Agua (Peruvian NGO)
ISRIC	International Soil Reference and Information Centre
ISWA	Institute for Sanitary Engineering, Water Quality and Solid Waste Management, University of Stuttgart
IWG	Institute for Water and River Basin Management, Karlsruhe Institute of Technology
IWRM	Integrated Water Resources Management
JASS	Junta Administradora de Servicios de Saneamiento (community-managed service providers for drinking water and sanitation in Peru)
JMP	Joint Monitoring Program
JU Lurín	Junta de Usuarios del Sector Hidráulico Lurín (Board of Users of the Hydraulic Sector Lurín in Peru)
KIT	Karlsruhe Institute of Technology
LAI	Leaf Area Index
LfULG	Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie (Saxonian state office for environment, agriculture and geology)
Lindley	Arca Continental Lindley S.A. (Peruvian company)
LTV	Landestalsperrenverwaltung Sachsen (Saxonian state office for dams)
MD	Municipalidad Distrital (District Municipality)
mHM	mesoscale Hydrologic Model
MINAM	Ministerio del Ambiente (Peruvian Ministry of Environment)
MINEDU	Ministerio de Educación (Peruvian Ministry of Education)
MINSA	Ministerio de Salud (Peruvian Ministry of Health)
ML	Machine Learning
MMCL	Mancomunidad Municipal de la Cuenca Lurín (Association of Municipalities in the Lurin Catchment)
MODIS	Moderate Resolution Imaging Spectroradiometer

Abbreviations

Abbreviation	Description
MP Huarochirí	Municipalidad Provincial Huarochirí (Municipality of Huarochirí Province)
MPN	Most Probable Number
MVCS	Ministerio de Vivienda, Construcción y Saneamiento (Peruvian Ministry for Housing, Construction and Sanitation)
MYPE	Micro y Pequeñas Empresas (SME - Small and Medium Enterprises)
NASA	National Aeronautics and Space Administration
NGO	Non-governmental organization
NTU	Nephelometric Turbidity Unit
OA CHIRILU	Observatorio del Agua Chillón Rímac Lurín (Platform of public and private partners for sharing information on water resources in the three catchments of Lima, Peru)
OECD	Organisation for Economic Co-operation and Development
OSM	OpenStreetMap
OTT	OTT Hydromet GmbH
P tot	Total Phosphorus
PE	Polyethylen
PEN	Peruvian Sol
PER	Peru
PFU	Plaque Forming Unit
PISCO	Peruvian Interpolation of the SENAMHI'S Climatological and hydrological data Observations
PNSR	Programa Nacional de Saneamiento Rural (National Program for Rural Sanitation of the Peruvian Ministry for Housing, Construction and Sanitation)
PS	Puesto de Salud (Health post)
PUCP	Pontificia Universidad Católica del Perú (Private University in Lima, Peru)
PVC	Polyvinyl chloride
PVL	Programa Vaso de Leche (social food assistance program in Peru)
RSF	Rapid Sand Filtration
SAC	Specific absorption coefficient in 1/m
SDG	Sustainable Development Goal
SEDAPAL	Servicio de Agua Potable y Alcantarillado de Lima (Public company for drinking water and waste-water services in Lima and Callao, Peru)
SENAMHI	Servicio Nacional de Meteorologia e Hidrologia (National Meteorological and Hydrological Service of Peru)
SENASA	Servicio Nacional de Sanidad Agraria (National Agricultural Health Service of Peru)
Sierra Azul	Fondo Sierra Azul (Program of the Peruvian Ministry for Agriculture)
SS	Suspended Solids
SSF	Slow Sand Filtration
SUNASS	Superintendencia Nacional de Servicios de Saneamiento (National Superintendency for Sanitation Services of Peru)
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement
TCC	Total Cell Counts
TDS	Total Dissolved Solids
TF	Trickling Filter
TIS	Total Impact Score
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon

Abbreviations

Abbreviation	Description
TRMM	Tropical Rainfall Measuring Mission
TRUST	Trinkwasserversorgung in prosperierenden Wassermangelregionen nachhaltig, gerecht und ökologisch verträglich: Entwicklung von Lösungs- und Planungswerkzeugen zur Erreichung der nachhaltigen Entwicklungsziele am Beispiel der Region Lima/Peru (Sustainable, fair and environmentally sound drinking water supply for prosperous regions with water shortage : Developing solutions and planning tools for achieving the Sustainable Development Goals using the river catchments of the region Lima/Peru as an example)
TRWR	Total Renewable Freshwater Source
TSS	Total Suspended Solids
TZW	TZW: DVGW Technologiezentrum Wasser (German Water Centre)
UASB	Upflow Anaerobic Sludge Blanket
UAV	Unmanned Aerial Vehicles
UNACEM	Unión Andina de Cementos S. A. A. (Peruvian company)
UNALM	Universidad Nacional Agraria La Molina (National Agrarian University in Lima, Peru)
UNDESA	United Nations Department of Economic and Social Affairs
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-HABITAT	United Nations Human Settlements Programme
UNI	Universidad Nacional de Ingeniería (National Engineering University in Lima, Peru)
UNICEF	United Nations International Children's Emergency Fund
UTEC	Universidad de Ingeniería y Tecnología (Private University for Engineering and Technology in Lima, Peru)
WHO	World Health Organization
WSP	Water Safety Plan
WWTP	Wastewater Treatment Plant
Yanbal	Yanbal Unique S.A. (Peruvian company)
ZIRIUS	Center for Interdisciplinary Risk and Innovation Studies, University of Stuttgart

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Integrated Water Management Solutions in the Lurín Catchment, Lima, Peru

Supporting United Nations' Sustainable Development Goal 6

With the 2030 Agenda for Sustainable Development, the United Nations have established a catalog of 17 Sustainable Development Goals (SDGs) to achieve a better and more sustainable future for all by 2030. One important aspect, formulated as Goal 6, is ensuring the availability and sustainable management of water and sanitation for all. Achieving SDG6 represents a challenge for planning, governance, and water management, especially in prosperous water-scarce regions, where water demand rises steadily and outgrows sustainable supply.

Using the example of the catchment area of the Río Lurín in Lima, Peru, the TRUST project demonstrated how interdisciplinary and transdisciplinary approaches could contribute to meeting the water management challenges that are related to achieving SDG 6 in prosperous regions facing water scarcity. The approaches cover the closely interlinked domains water resources, water use, and water management. For each domain, we set up a comprehensive data base, conducted local analyses, and developed integrated concepts taking the river basin perspective into account. The concepts covered drinking water supply, safe wastewater treatment and disposal, and water reuse. They were developed in close cooperation with local actors and national authorities. The methods and tools can be transferred to other regions of the world with similar challenges.

This TRUST Report is intended as a manual to help decision-makers and water management professionals to develop and implement locally adapted solutions for sustainable water management.

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