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Conceptual Framework for Scenarios Development in the Water Futures and Solutions project

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Approved by

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Director General CeO, IIASA

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Contents

Abstract

The major purpose of the Water Futures & Solutions (WFaS) initiative is to develop a set of adaptable, resilient and robust solutions and a framework to facilitate access to and guidance through them by decision makers facing a variety of water-related challenges to sustainable development, and a set of optional pathways to achieve plausible sustainable development goals by 2050.

The WFaS Initiative addresses the multidimensional aspects of the water system and is guided by stakeholders representing these various aspects. The Initiative views freshwater systems as being strongly interweaved with human activities (Economy, Society) and Nature as a whole. Dynamics and health of freshwater systems is critical to human well-being. The Initiative will go beyond scenario production and model comparisons and will focus on exploring solutions and necessary innovations to address the growing water challenges. Solutions can be combinations of technological innovations, regulatory approaches, management or institutional changes that improve the balance of water supply and demand, improve water quality, or reduce water-related risks for society. Solutions will often be embedded in and cut across all sectors of social and economic activities. In order to represent the aspirations and interdependencies as described above, the conceptual framework has been developed, to be used both within the project and to communicate project results to the target audiences.

This document describes this conceptual framework that will be used:

- to support development of qualitative water scenarios
- to identify and select critical dimensions of the water scenarios
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- to support collaboration between project and stakeholder groups
- to facilitate presentation of results to target audiences

The WFaS conceptual framework is developed using the ‘concept maps’ technique (Cañas and Carff, 2005; Novak and Cañas, 2006b). Concept maps method was develop to represent knowledge in an organized way. It allows practitioners to represent concepts and specific relationships between concepts. It is flexible enough to adapt to different knowledge domains to support better understanding and communication between individuals and groups from different backgrounds.

About the Authors

William Cosgrove

William (Bill) Cosgrove joined IIASA's Water (WAT) Program as a Senior Research Scholar in March 2012. His initial work has been related to the integration of the next phases of a world water scenarios project into IIASA's Water Program.

Cosgrove received his B.Eng. and M.Eng. (sanitary engineering) and Honorary Doctorate of Science from McGill University and is an Honorary Fellow of UNESCO-IHE. He has followed other graduate courses in economics, management and cross-cultural studies at McGill and Georgetown Universities and the Harvard Business School. He is Manager of the World Water Scenarios Project of the UN World Water Assessment Program, a member of the Calouste Gulbenkian Foundation Think Tank on Water and the Future of Humanity, and of several professional associations including the Association of Professional Futurists.

Guenther Fischer

Professor DI Günther Fischer is a senior researcher in land use systems of the Food and Water thematic area at IIASA. He also holds the position of adjunct professor in the Department of Geography at the University of Maryland, USA. His main fields of research are mathematical modeling of ecological-economic systems, econometrics, optimization, applied multi-criteria decision analysis, integrated systems and policy analysis, spatial agro-ecosystems modeling, and climate change impacts and adaptation. He participated in the development of IIASA's world food systems model and was a key contributor to several major food and agricultural studies: On welfare implications of trade liberalization in agriculture; on poverty and hunger; on biofuels and food security; on the climate-water-food-energy-ecosystem nexus; and on climate change and world agriculture. He is collaborating with the United Nations Food and Agriculture Organization (FAO) on the development and application of the Agro-Ecological Zones methodology and has contributed to major FAO agricultural perspective studies, to IPCC assessment reports, the Millennium Ecosystem Assessment, WSSD Johannesburg Report Climate Change and Agricultural Vulnerability.

Professor Fischer is recognized as one of 23 IIASA scientists that have contributed to the large body of IPCC reports. The Nobel Peace Prize (2007) was awarded to the Intergovernmental Panel on Climate Change (IPCC) and Al Gore for "their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

Martina Flörke

Dr. Martina Flörke is a senior researcher at the Center for Environmental Systems Research (CESR) at the University of Kassel in Germany and is, since 2011, heading the GRID-Water group. Her research focuses on model development, especially with a view to water use, and project management. All of her research interests are related to global change, climate change and water resources; The impact of global change on freshwater resources: Where are the hotspots and where will they be in the future?; Climate change and its impact on the energy sector.; Indicator development.; Further model improvements and developments of WaterGAP model(s).; Temporal dynamics of different water use sectors: past - present - future.; Urbanisation and water use.; Vulnerability and adaptation strategies.

Since the beginning of the WFaS Initiative Dr. Flörke has been actively involved in the development of its research.

Eva Hizsnyik

Eva Tothne Hizsnyik joined IIASA's former Land Use Change and Agriculture (LUC) Program, now Ecosystems Services and Management (ESM) Program, as a Research Scholar in 2003. She holds a master's degree in economics, and has been dealing with socioeconomic aspects of global environmental change for several years. Her current responsibilities include data mining, updating and harmonizing databases for various ongoing research projects, and estimating and analyzing possible socioeconomic impacts of land use and land cover change.

Piotr Magnuszewski

Piotr Magnuszewski has a background in mathematics (MSc) and physics (PhD). He later gained experience in the area of complexity science. He is presently working in the Water and the Risk, Policy and Vulnerability (RPV) Program of IIASA. He is furthermore co-founder and managing director of the ISIS Academy/Centre for Systems Solutions.

Dr. Magnuszewski has been working for many years as a systems modeler, professional trainer, facilitator and researcher. He is particularly involved in linking theory and practice, science and policy, knowledge and action through diverse systems and knowledge management tools. He has been applying and teaching systems tools with diverse groups of scientists, NGOs, businesses and administration in many countries.

Dr. Magnuszewski was engaged in many international projects on resilience adaptive management of complex socio-ecological systems. In this context he facilitated multi-party collaboration. He also developed and applied, in a participatory way, a range of system dynamics models. He designed and applied many simulation and role-playing games as research and educational tools. He is author of many research and educational publications.

Claudia Pahl-Wostl

Claudia Pahl-Wostl is professor for resources management, an endowed chair of the German Environmental Foundation, at the Institute for Environmental Systems Research in Osnabrück, Germany.

She is an internationally well known expert in adaptive management, water governance and participatory integrated assessment and agent based modelling. Before moving to USF Claudia Pahl-Wostl worked for more than ten years in the field of mathematical modelling, integrated assessment and human ecology at the Swiss Federal Institute for

Science and Technology, Zürich and the Swiss Federal Institute for Aquatic Science and Technology, EAWAG, one of the leading water research institutes in Europe.

Angelika Scherzer

Ms. Deirdre Zeller is the program assistant for the IIASA Water program, where she fulfills program coordination activities. Ms. Scherzer has more than ten years of working experience in international organizations and NGOs in Austria and abroad, including developing countries. In her positions she coordinated the implementation of projects and programs dedicated to poverty reduction, food security, agricultural development, migration, return and reintegration as well as peacebuilding and advocacy for the concerns of less and least developed countries. Ms. Scherzer holds a Masters degree in International Relations & Development Studies from the University of East Anglia, a postgraduate diploma in International Development Studies from the Polytechnic University of Catalonia and an undergraduate degree in Business Administration from the International Business College in Vienna.

Andrew Segrave

Dr. Andrew Segrave is Scientific Researcher and the KWR Watercycle Research Institute. He spearheads scientific futures studies at KWR Watercycle Research Institute. As coordinator responsible for the thematic research on trends and future perspectives for the Joint Water Sector Research Programme of the Dutch water companies, Andrew also has much experience at applying methods for horizon scanning and strategic planning in practice. His work and active contribution to the WFaS Initiative has been substantial to the development of this and other reports.

Geza Toth

Geza Toth has been a research affiliate with IIASA since 2007. He served as the Program Officer of IIASA's Greenhouse Gas Initiative and as a Research Assistant with the Atmospheric Pollution and Economic Development (APD) Program, working within the Policy Assessment Framework between 2007 and 2010. He then moved to IIASA's Ecosystems Services and Management (ESM) Program, specializing in mitigation strategies for land-based systems, including agriculture and forestry. In his last position at IIASA he was affiliated with IIASA's flagship activity, the Water Futures and Solutions Initiative (WFaS), where after an initial period devoted to program coordination- he carries out his own research activities on pilot case studies and real world implications of systems analysis.

Currently he is Project Developer at *Ferrero* Trading Lux S.A. and maintains a guest research contract at IIASA.

Sylvia Tramberend

Sylvia Tramberend is a research scholar in IIASA’s interdisciplinary and policy oriented research focused in the food and water thematic area. Since joining the Land Use Change and Agriculture Program in 1997 (Ecosystems Services and Management Program as of

2011), she has contributed to research in systems analysis of agriculture, land use change and ecosystem studies. In 1994, Dr. Tramberend participated in IIASA’s Young Summer Scientists Program, after which she continued working as a research scholar with the Program "Regional Material Balance Approaches to Long-Term Environmental Planning".

Her responsibilities as a land use and GIS expert have included the development of large spatial databases serving the modeling and analysis needs in the areas of food-environment-bioenergy-water linkages, food-system analysis, land use and water scenarios and environmental transition. She was involved in Agro-Ecological Zones Methodology assessments for agricultural development planning, worked on several assessments of biofuels and food security, and the mobilization of resources for the bio-economy. In sustainable consumption research she has been a principal investigator in analysis tracing embodied land use and deforestation in agricultural and forestry products from primary production to final utilization. The geographic focus of her research has been both global and regional (e.g. Europe, China, and Brazil).

Michelle van Vliet

Michelle T.H. van Vliet is a Postdoctoral Research Scholar with IIASA’s Water (WAT) Program. She is participating in the World Water Scenarios Project and focusses on the ‘water-energy nexus’ (i.e. complex linkages among water and energy security) under future climate and socio-economic changes. Global and regional water assessments of water resources and cross-sectoral water uses are performed with the aim to develop management strategies for sustainable water, food and energy supply under future climate and socio-economic changes.

Since January 2013, she has been working as a postdoctoral researcher both at IIASA and at Wageningen University, the Netherlands.

David Wiberg

David Wiberg is the Acting Director of IIASA’s Water Program and is managing the Water Futures and Solutions Initiative (WFaS), applying systems analysis to build and explore with stakeholders consistent scenarios of the freshwater system across scales and sectors, and exploring the synergies and tradeoffs of intervention options in order to inform decisions focused on more effective and robust water management.

Dr. Wiberg received a degree in physics, with an economics minor, from Gustavus Adolphus College and master’s and PhD degrees in civil engineering, water resource engineering and management, from the University of Colorado, Boulder. He designed river basin management software as a consultant for the Bureau of Reclamation, US DOI, and also consulted with the EPA and DOE in the USA. In 1997 he started working with IIASA in the Land-Use Change and Agriculture program, assessing the impact of land use and climate changes on basin water resource availability, demand, required storage capacity, development costs and management options, as well as helping develop the Harmonized World Soil Database and Global Agro-Ecological zoning methodologies and assessments. He consulted concurrently for the World Water Assessment Program and the Dialogue for Water and Climate, and is now helping to launch IIASA’s Water

Program and the Water Futures and Solutions Initiative, incorporating water science into IIASA's integrated assessments. Dr. Wiberg's primary fields of interest are efficient and sustainable water management strategies, water modeling and the development of decision support tools, and climate change impact assessments.

Paul Yillia

Paul T. Yillia (Dr. techn.) joined the Water (WAT) Program at IIASA in November 2012 to support research on the Water-Energy Nexus and the World Water Scenarios Project. Previously, he was a research and teaching assistant at the Vienna University of Technology, Institute for Water Quality, Resources and Waste Management, where he accomplished joint research and transnational exchange of knowledge and skills on water science and technology, especially in developing countries and countries in transition. Prior to this, Dr. Yillia undertook various assignments in the Netherlands with UNESCO-IHE Institute for Water Education and Cap-Net (Capacity Building Network for Integrated Water Resources Management), with progressive responsibility in training materials development, research, education and partnership in the water sector. He was also lecturer and research fellow on aquatic systems at the University of Sierra Leone and has undertaken various capacity building responsibilities within the framework of development co-operation in several countries in sub-Saharan Africa.

With a mixed background in applied science, Dr. Yillia has a range of research interests in the water sector, from natural and induced processes and applications in aquatic systems to water quality implications on human health and the environment. His research and publication record covers a range of topics, including water resources evaluation and planning, water-related health risk assessment and catchment vulnerability assessment and management.

Deirdre Zeller

Ms. Deirdre Zeller was formerly associated with IIASA as program assistant for the Water program.

Conceptual Framework for Scenarios Development in the Water Futures and Solutions project

1 Introduction

The WFaS Initiative addresses the multidimensional aspects of the water system and is guided by stakeholders representing these various aspects. The Initiative views freshwater systems as being strongly interweaved with human activities (Economy, Society) and Nature as a whole. Dynamics and health of freshwater systems is critical to human well-being. The Initiative will go beyond scenario production and model comparisons and will focus on exploring solutions and necessary innovations to address the growing water challenges. Solutions can be combinations of technological innovations, regulatory approaches, management or institutional changes that improve the balance of water supply and demand, improve water quality, or reduce water-related risks for society. Solutions will often be embedded in and cut across all sectors of social and economic activities. In order to represent the aspirations and interdependencies as described above, the conceptual framework has been developed, to be used both within the project and to communicate project results to the target audiences.

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2 Description of the Conceptual Framework

The framework visualizes (see Figure 1) Coupled Human-Natural Freshwater System as one face of a cube that is strongly interweaved with other face representing human activities (Economy, Society) and Nature as a whole. The dynamics of this complex Freshwater System is also critical to human well-being. The Water Futures & Solutions initiative will go beyond producing scenarios but will also provide solutions (another face) for the growing water crisis. Again, the solutions developed, will be embedded in social and economic activities but for conceptual clarity they are represented by a separate face. Any element belonging to the Coupled Human-Natural Freshwater System face belongs also to one of the areas of the third face: Nature, Society, Economy or Human Well-being. Any specific solution is at the same time a part of Freshwater System and one of the above mentioned areas on the third face.

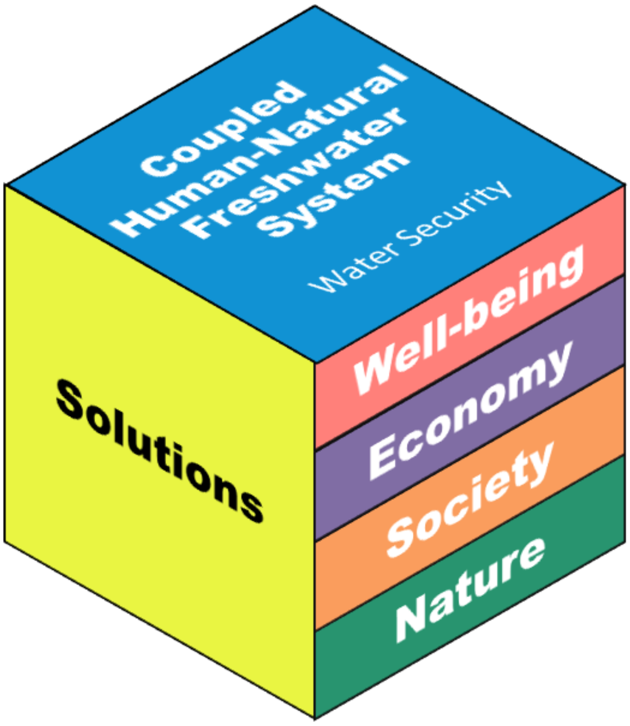

Figure 1. Multidimensional character of the scenario framework. In order to provide appropriate focus, The Coupled Human-Natural Freshwater System and Solutions are visualized as separate faces of the cube.

The most important indicator of the Freshwater System is Water Security defined as *"the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environment and economies"* [Grey and Sadoff, 2007]. Recently an alternative, but related, definition has been proposed for water security in terms of risk *"a tolerable level of water-related risk to society"* [Grey et al, 2013].

For the purposes of developing water scenarios, the driving forces and important outcomes considered to be the most dominant in determining the sustainability of the world water system within the time horizon of the exercise were grouped into a set of clusters each of them assigned to one of the components of Figure 1.

The multidimensional water system presented in Figure 1 is represented in a 2-dimensional space of Figure 2 with main drivers (Nature, Economy, and Society) at the bottom, freshwater systems dynamics and resulting outcomes in the middle and well-being embracing water security at the top. The diagram represents a systemic arrangement of drivers in the areas of *Nature*, *Society* and *Economy,* their relations to *Freshwater Systems,* and its contributions to *Well-being*. Water security, embracing ecosystems dimension, is a central criteria to assess the desirability of the scenarios and benefits of proposed solutions.

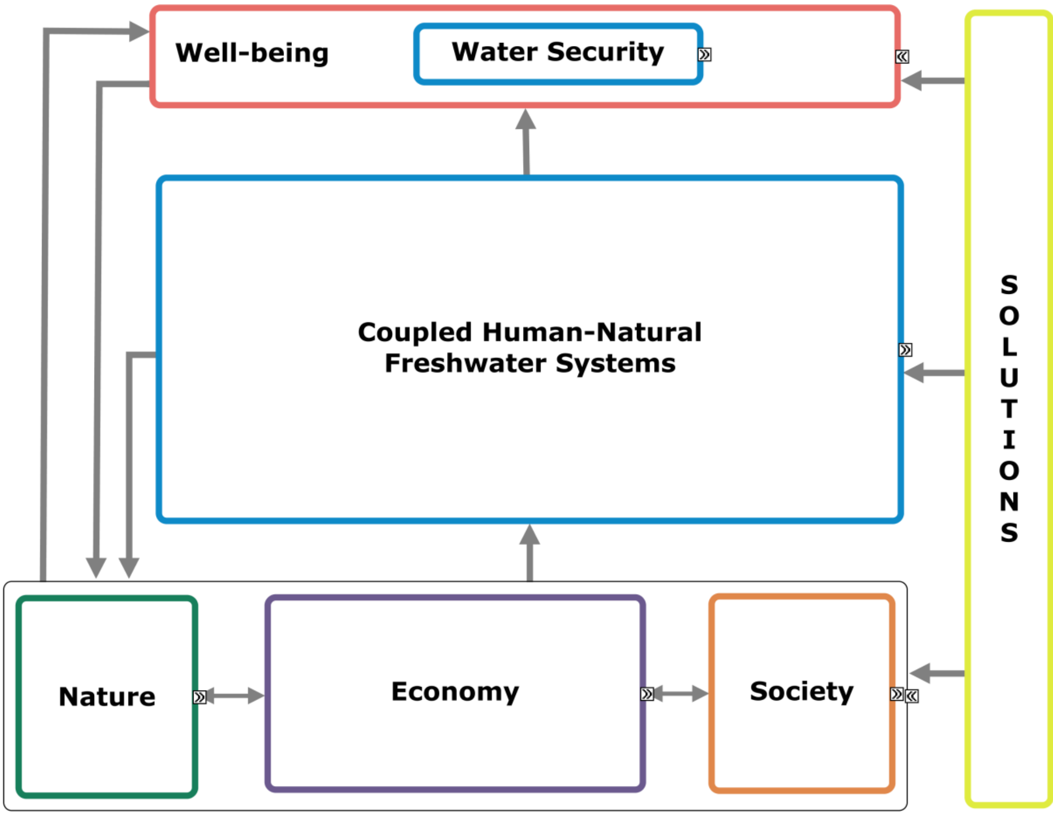

Figure 2. The scenario framework represented in two dimensions.

The framework is further expanded in Figure 3. It shows that Water Security is critical to a number of different dimensions of well-being (top box in Figure 3). The diagram also shows that water security and freshwater ecosystems health are exposed to a number of risks such as water shortage, floods, water pollution, and river and catchment disturbance resulting both from natural dynamics as well as alteration of freshwater systems by human activities. Freshwater resource dynamics and water use (withdrawals and consumption) is driven by a range of diverse factors grouped together in the areas of Nature, Economy and Society (only the major factors relevant for water scenarios are shown here). Each of the drivers in Figure 3 represents the entire cluster of factors that together with causal links between them can be further explored in order to link them with water and solutions variables. These clusters correspond to the groups of factors used in the IPPC-SSP narratives, too.

Freshwater Systems box in Figure 3 provides a focus on Dynamics and Use of Freshwater Resources that includes both natural dynamics of river systems and effects of human alterations. It encompasses different water uses (some of them resulting in return flows, some of them in consumptive uses). Natural Freshwater Resource Dynamics together augmented by water infrastructure determines water availability for different demands – both human (agriculture, energy, industry and household) as well as ecosystems (environmental flows requirements). In each of these sectors actual water use compared to demand determines potential water shortage. Actual water shortages depend also on water allocation. Overall freshwater system dynamics, including time and variability dimensions (within the year and between years) determines various threats for water security, that can be related to both shortage and excess of water as well as its quality. These threats when combined with specific vulnerabilities and existing solutions to tackle them (e.g. virtual water trade) can be used to calculate water related risks. When combined with tolerable risk levels, that are different for different societies and groups, they provide a measure of Water Security [Grey et al, 2013].

A more detailed representation of freshwater resource dynamics and use as well as its links with driving forces are presented in the sub-diagrams (Figures 7 to 14).

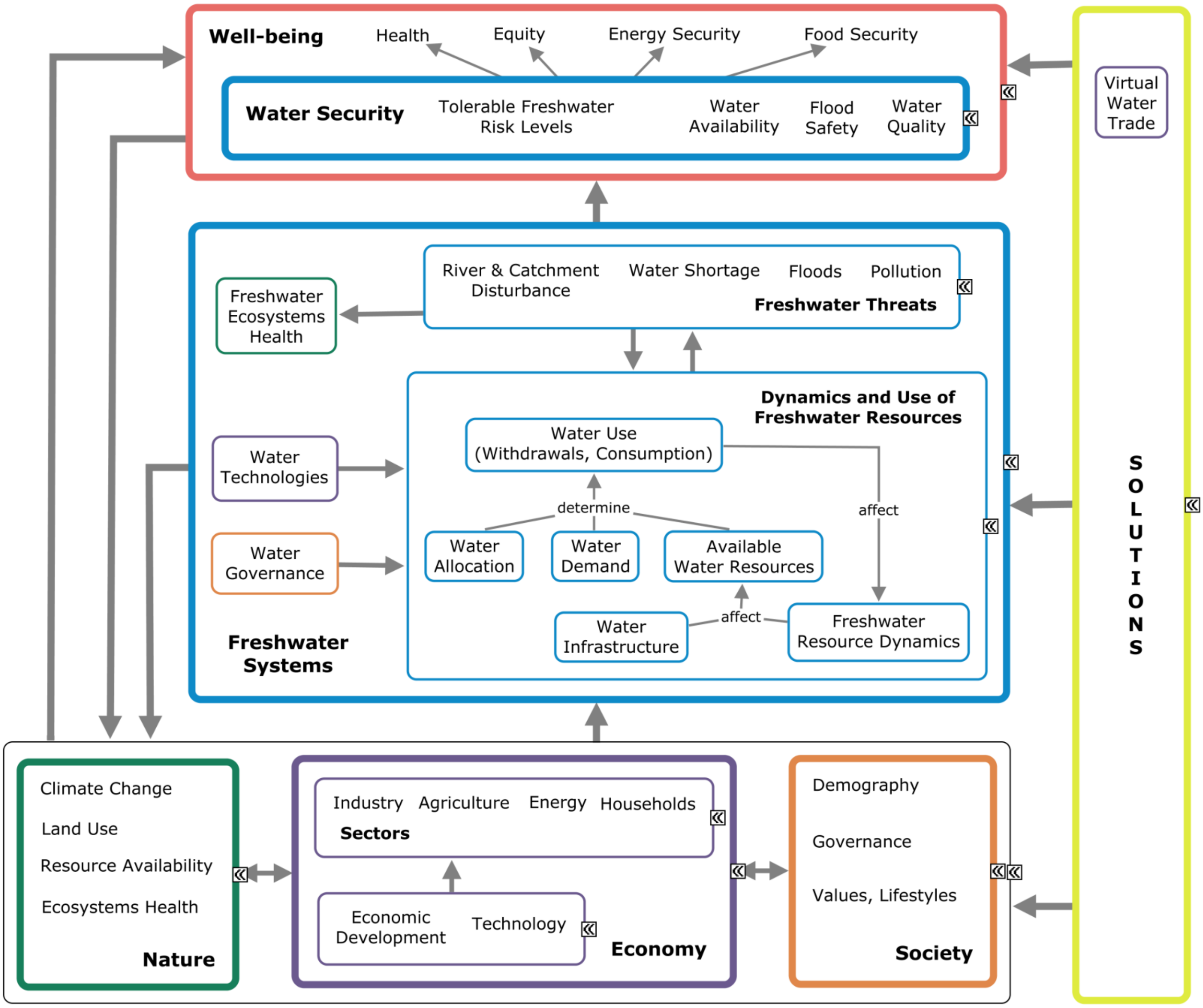

Figure 3. Key drivers and causal links affecting water security. See the text for further explanation.

Solutions that will be developed in the project are located on the right side of Figures 2 and 3. One needs to remember that this two-dimensional view distorts to some extent the actual system – the specific faces of the cube (as shown in Figure 1) are actually 'penetrating' one another. For example 'Policies and Institutions' represented in the Society component, when analyzed from Water perspective, at the same time belongs to Freshwater Systems. Human Water Security is placed in one of the Freshwater Systems boxes although it is, at the same time a part of the Human Well-being. Similarly, Freshwater Ecosystem Health belongs also to Nature. Further, 'Solutions' that are depicted as a separate box will be placed in the specific areas of Society, Economy, Nature, and Freshwater Systems, respectively. Arrows indicate causal relationships between factors. Note that although the diagram is arranged to show the progression from drivers at the bottom, to outcomes at the top, there are many reciprocal links (feedbacks) that contribute to the complex dynamics of the whole system. All factors discussed here are to some extent interlinked; thus, Figure 3 is clearly a prioritized simplification made for the purpose of clarity.

3 Hydro-economic conditions

All dimensions presented in the conceptual framework may have different values depending on specific situation of a region or a country. In order to avoid averaging on the global level, that may strongly distort future narratives, the scenarios will be developed for four different categories conditions that countries or regions belong to (Figure 4). The same global narrative may play out differently in different conditions: complexity and risk vs (water-related) investments in infrastructure, institutions and information [Grey et al, 2013].

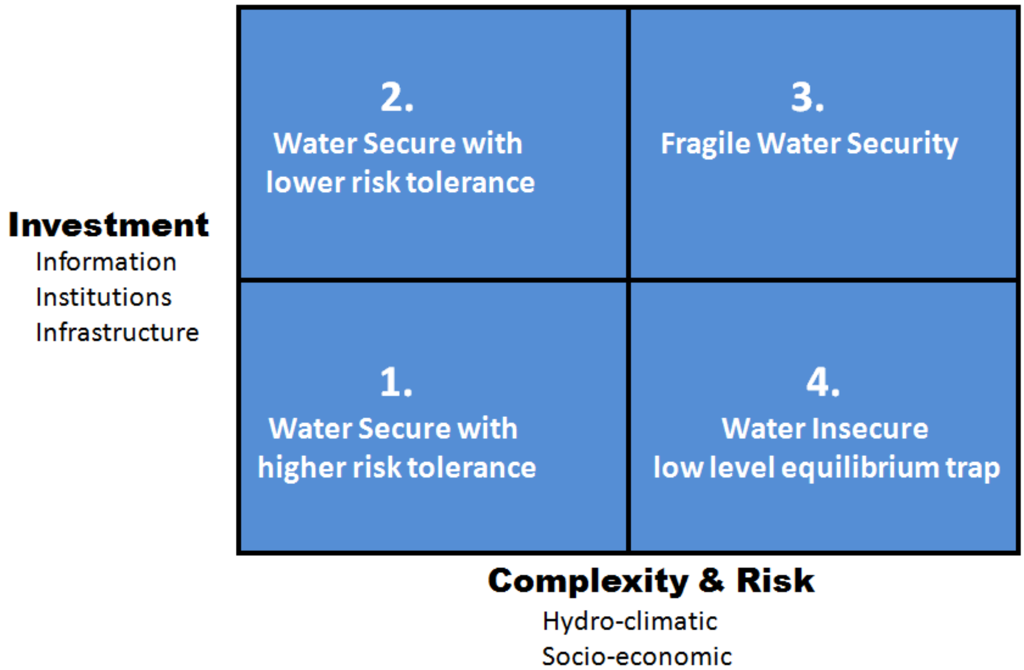

Figure 4. Four aqua-economic conditions differentiating global scenarios

Biophysical conditions resulting in poor water availability and /or high within-year and between-years variability require much bigger effort to manage water resources effectively. Water-related investments are strongly correlated with economic welfare. Countries who happen to be in a high water complexity condition without adequate economic means for necessary investments often stay in water insecure trap preventing social and economic development.

4 Critical Dimensions

Critical dimensions are selected dimensions, representing system performance that will be used for evaluation of scenarios and solutions (see Figure 5).

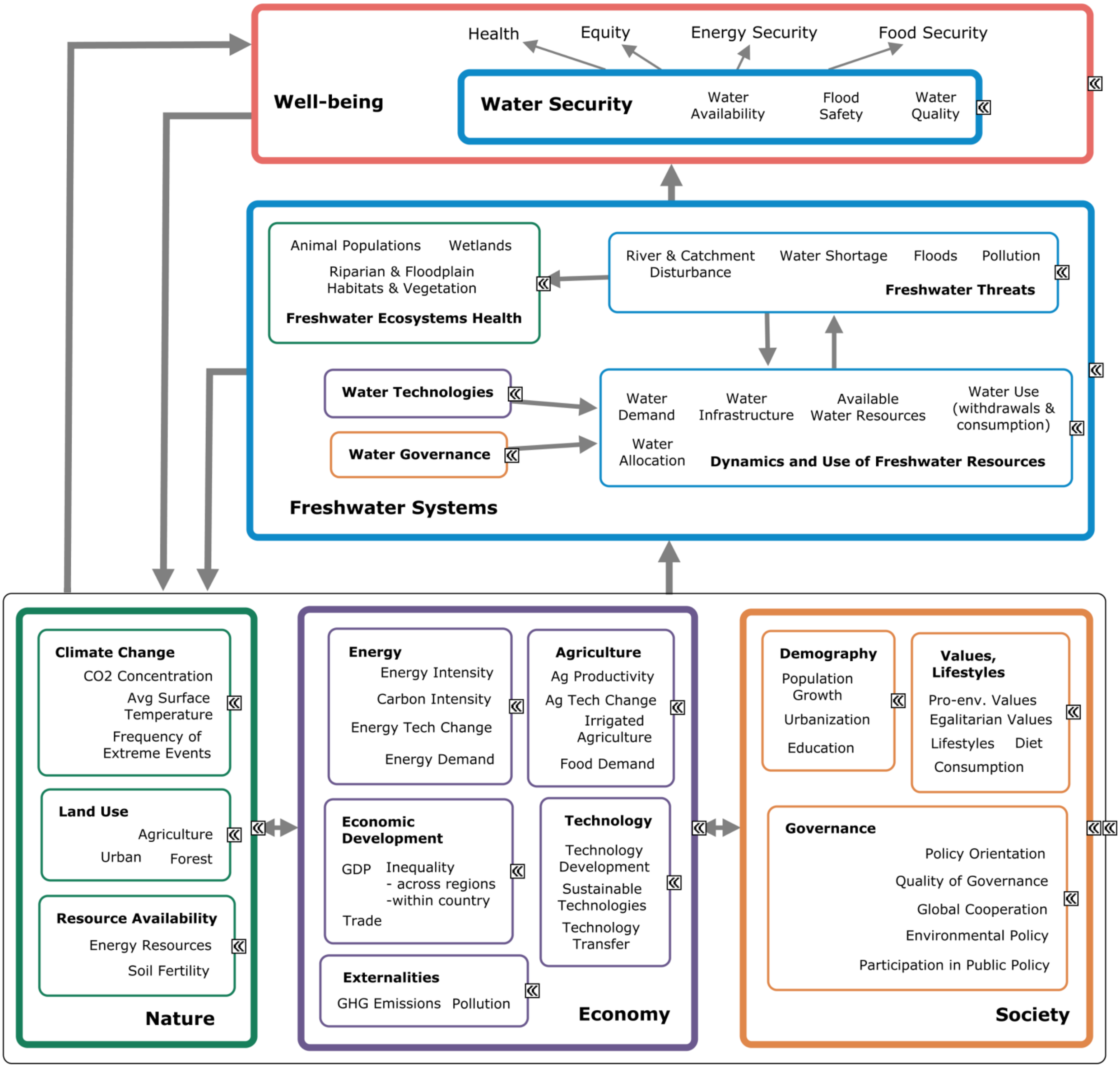

Figure 5. Critical Dimensions for the evaluation of scenarios results.

They are primary quantifiable indicators of water security as well as its drivers and impacts. They show the risks or benefits to society of policy and management decisions. Dimensions in the Well-being and Freshwater Ecosystem Health boxes will be used to evaluate the desirability and sustainability of the scenarios. Dimensions in Freshwater Systems box provide water specific drivers that lead to water security or its lack. Dimensions contained in the Nature, Economy and Society boxes represent important and uncertain factors, and will be used to explore a range of possible futures. Such exploration is necessary to develop robust solutions that work in these futures. The critical dimensions, as represented on Figure 5 do not portrait all interactions between different factors (that is the purpose of the framework diagram in Figures 3 and 6-14). Instead they provide specific dimensions to span the spaces for exploration of uncertainties and evaluation.

5 The expanded view of Freshwater Systems

All the boxes in Figure 3 can be further expanded. Figure 6 presents expanded view of Freshwater Resources.

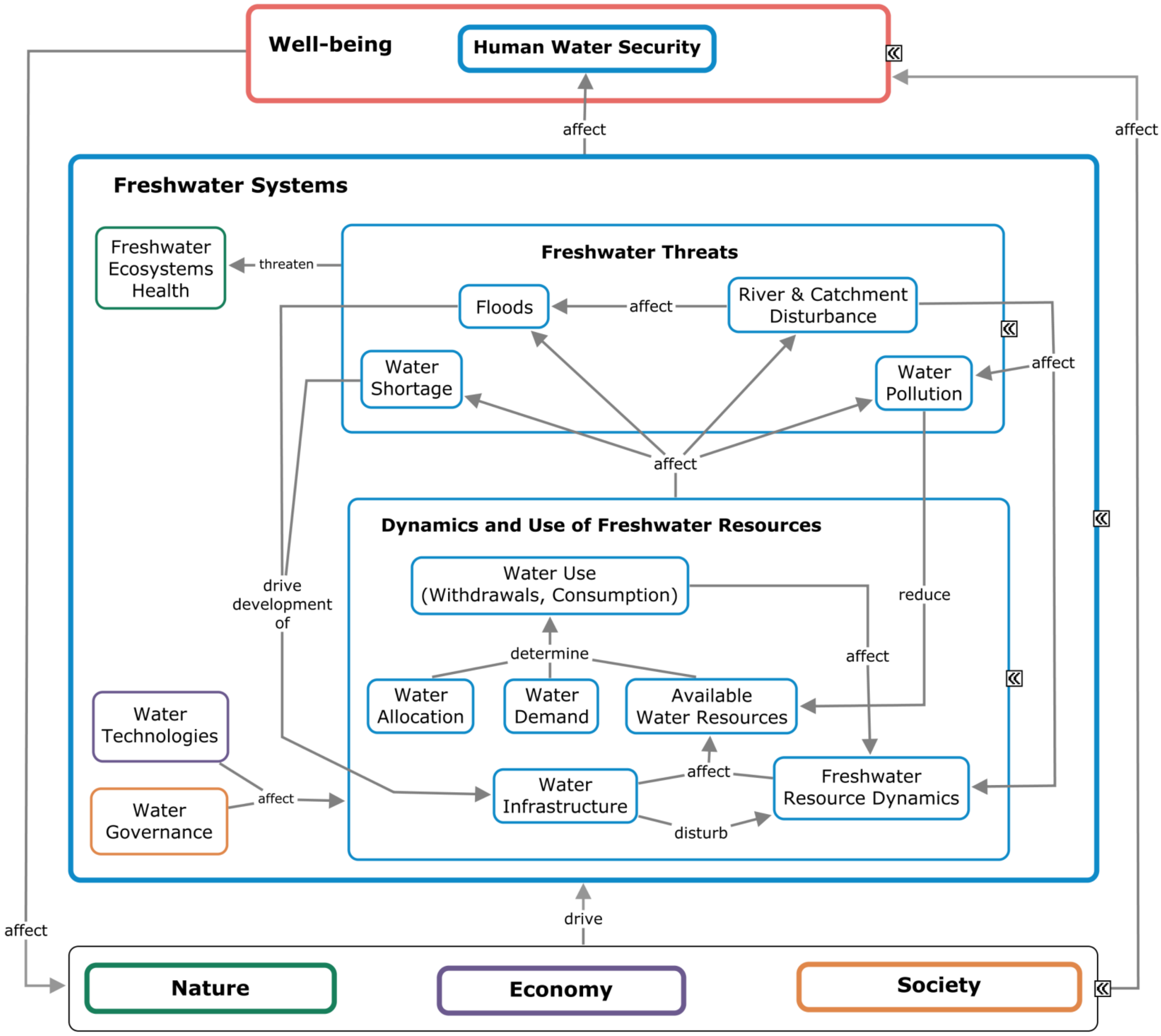

Figure 6. The Conceptual Framework – expanded view of Freshwater Systems

Freshwater Resource Dynamics is a key factor determining *Available water resources* that can be further increased by developing and maintaining *water infrastructure* such as dams, reservoirs, canals and irrigation systems. *Available water resources* can be decreased for the reason of inadequate water quality caused by *pollution*. The actual water supply (*water use*) is determined jointly by *available water resources* and *water demand*. *Water demand* (agriculture, energy, industry and households) is driven by developments in s*ociety* and *economy* and needs to maintain environmental flows. It can be reduced by using efficient water technologies and appropriate water governance. W*ater use* (w*ithdrawals* and *consumption)* is driven by the human activities that can be disaggregated into the categories used for water demand. The amount of water used in different sectors as well as water for ecosystems depends strongly on water allocation determined by water governance or lack thereof. *Water shortage* may becomes a constraint on such human activities as *economic development*, production and *human wellbeing*. High rates of water use disturb freshwater dynamics, increase river pollution and lead to water shortage for people and ecosystems downstream. Most responses to w*ater shortage* in developed countries focused on *water infrastructure* development that improves human water security but leads to river and catchment disturbance and high maintenance costs. *River and catchment disturbances* driven by economic activities affect *flood risk* in multiple ways. On the one hand flood protection infrastructure (dikes and reservoirs – a part of water infrastructure) reduces flood risk for target population. But disruptions in freshwater dynamics caused by all types of water infrastructure do not neutralize flood risk completely but rather shifts it in time and space. Moreover false sense of security from engineered flood protection drives floodplain development eventually leading to higher flood damages and very high costs of water infrastructure maintenance. There is a clear need for alternative pathways to address pressing water security threats in many regions of the World without getting into the traps that already have been recognized.

The more detailed conceptualization of Freshwater Resources and Water Use is shown in Figure 7.

The determinants of water demand in specific subsectors are shown in figures 8, 9,10 and 11.

Pollution and water quality issues are shown in Figure 12.

River and Catchment Disturbance issues are shown in Figure 13.

Elements of Water Infrastructure are shown in Figure 14.

6 Freshwater Resource Dynamics and Water Use

The stock of f*reshwater in rivers, wetlands, lakes and reservoirs* is supplied by r*unoff* originating from *rainfall* and *snowmelt*. This stock is depleted naturally through o*utflow to the sea* and e*vapotranspiration*. The natural cycle which regularly replaces water in this stock is modified by human-induced *water withdrawals*. Part of the water withdrawn is consumed (*consumptive use*) for a variety of purposes. The remaining water forms a *return flow*, which may become contaminated. As water flows downstream it can be used repeatedly provided that its quality does not deteriorate below certain standards for particular water uses.

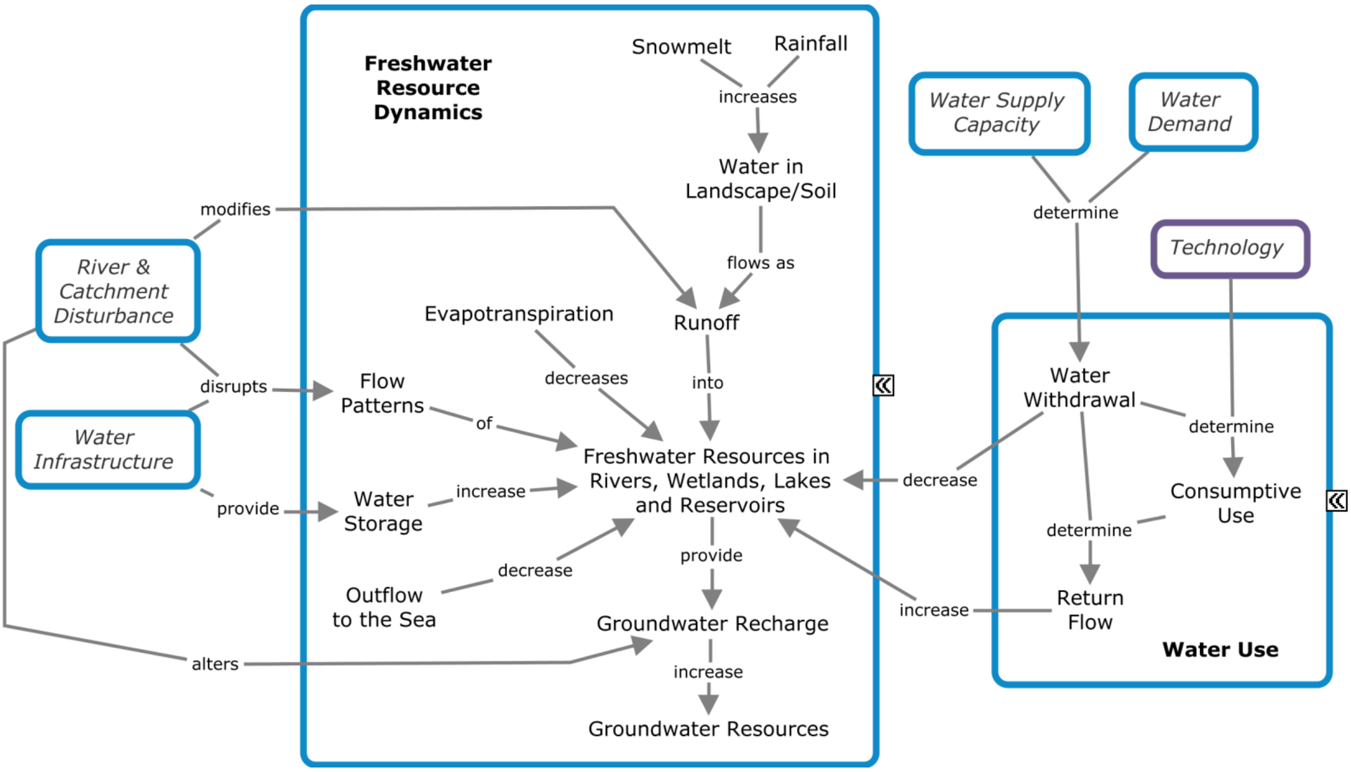

Figure 7. Freshwater Resource and Water Use Modules

7 Determinants of Water Demand

Aggregated water demand contains domestic, agricultural, energy and industrial components and includes water demand for ecosystems. The method of determining water demand is taken from (Alcamo and Doll 2003a, 2003b), (Alcamo et al. 2000).

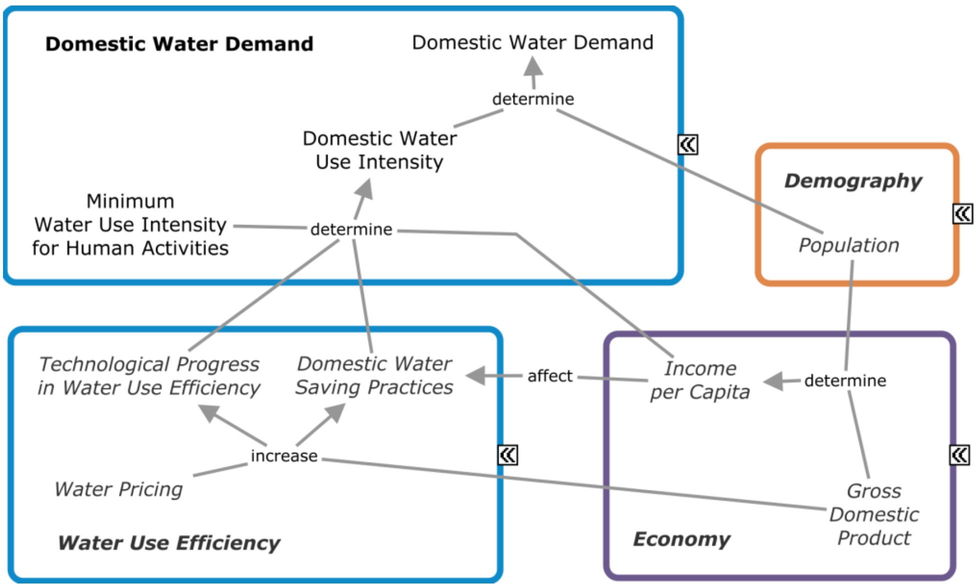

Figure 8. Determinants of domestic water demand.

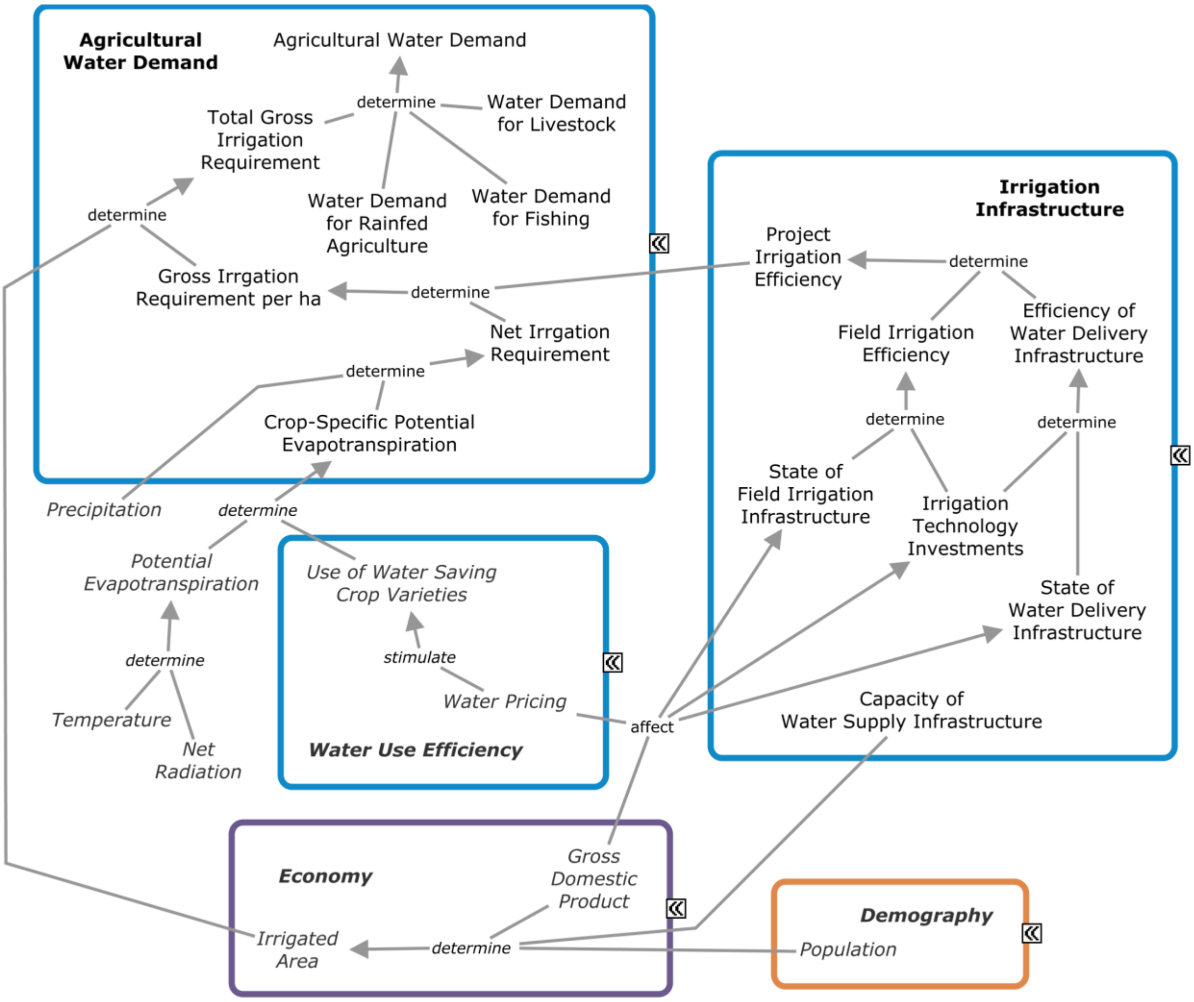

Figure 9. Determinants of agricultural water demand

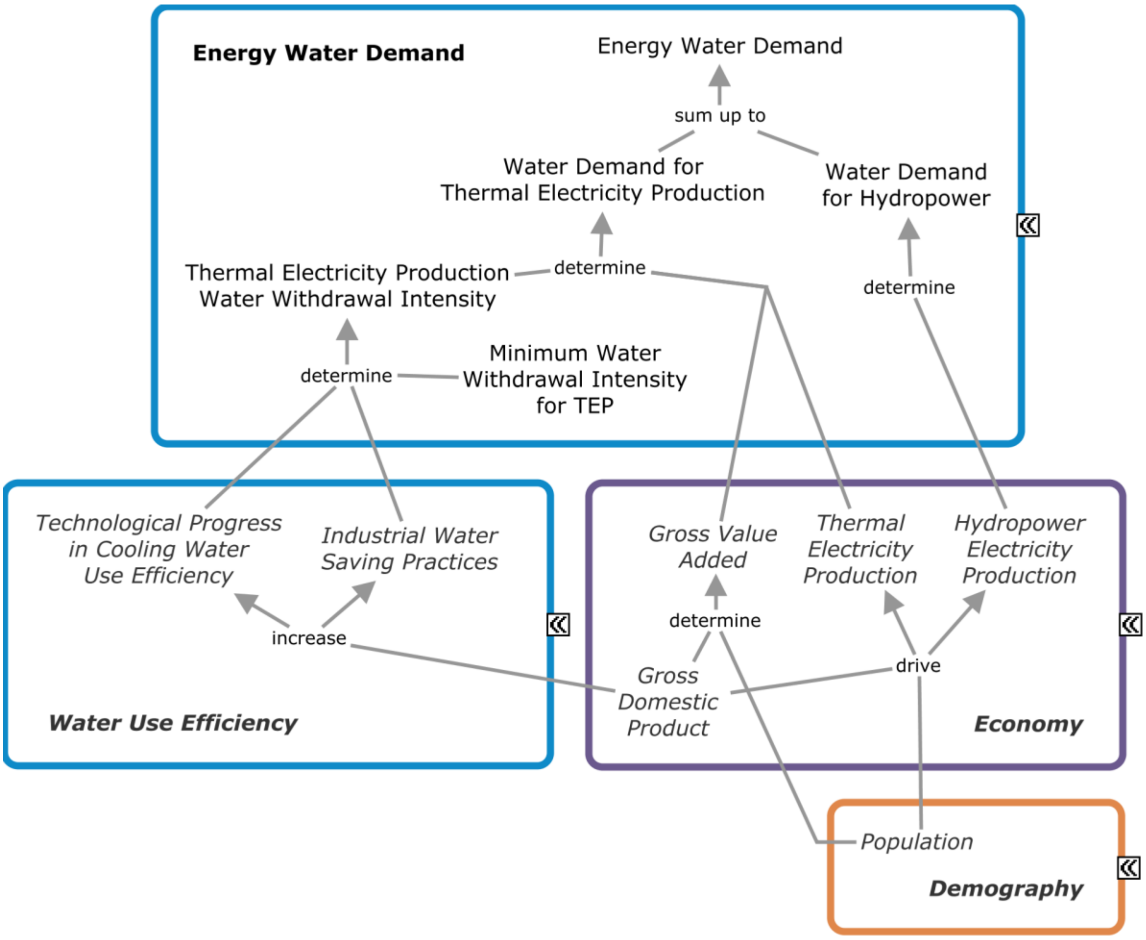

Figure 10. Determinants of energy water demand.

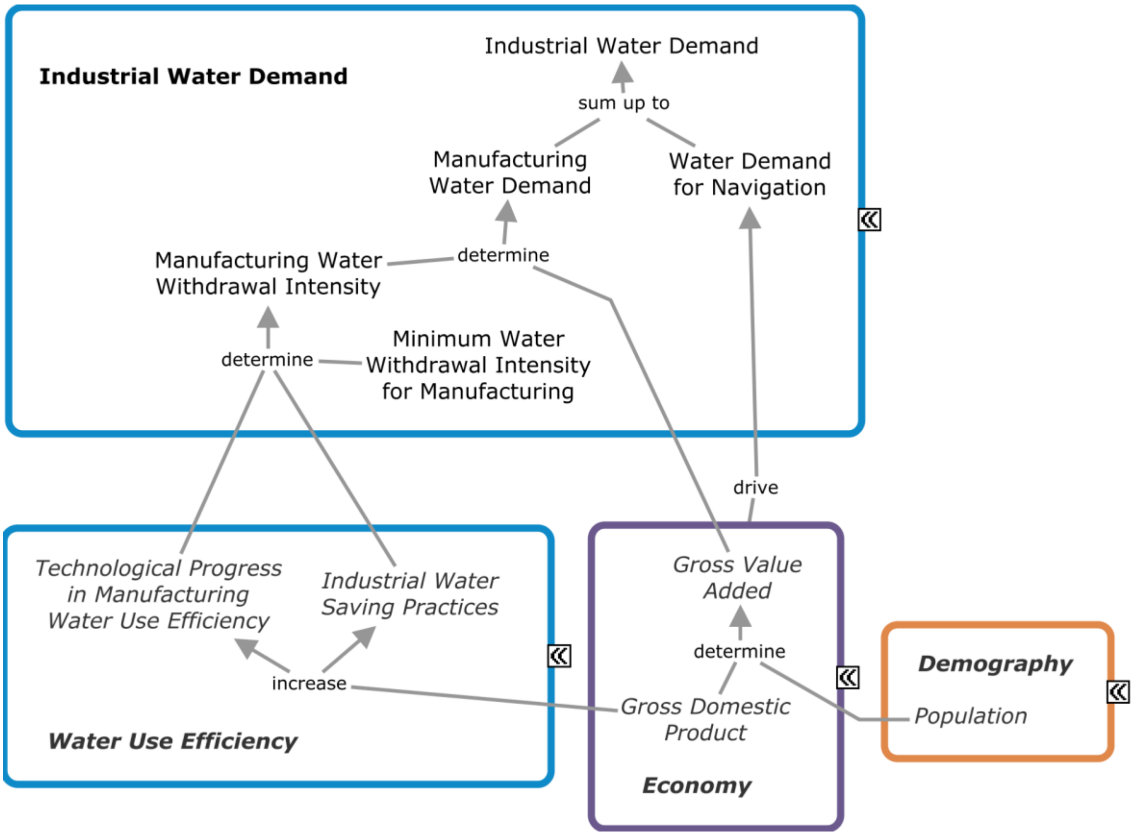

Figure 11. Determinants of industrial water demand.

8 Water Quality and Pollution

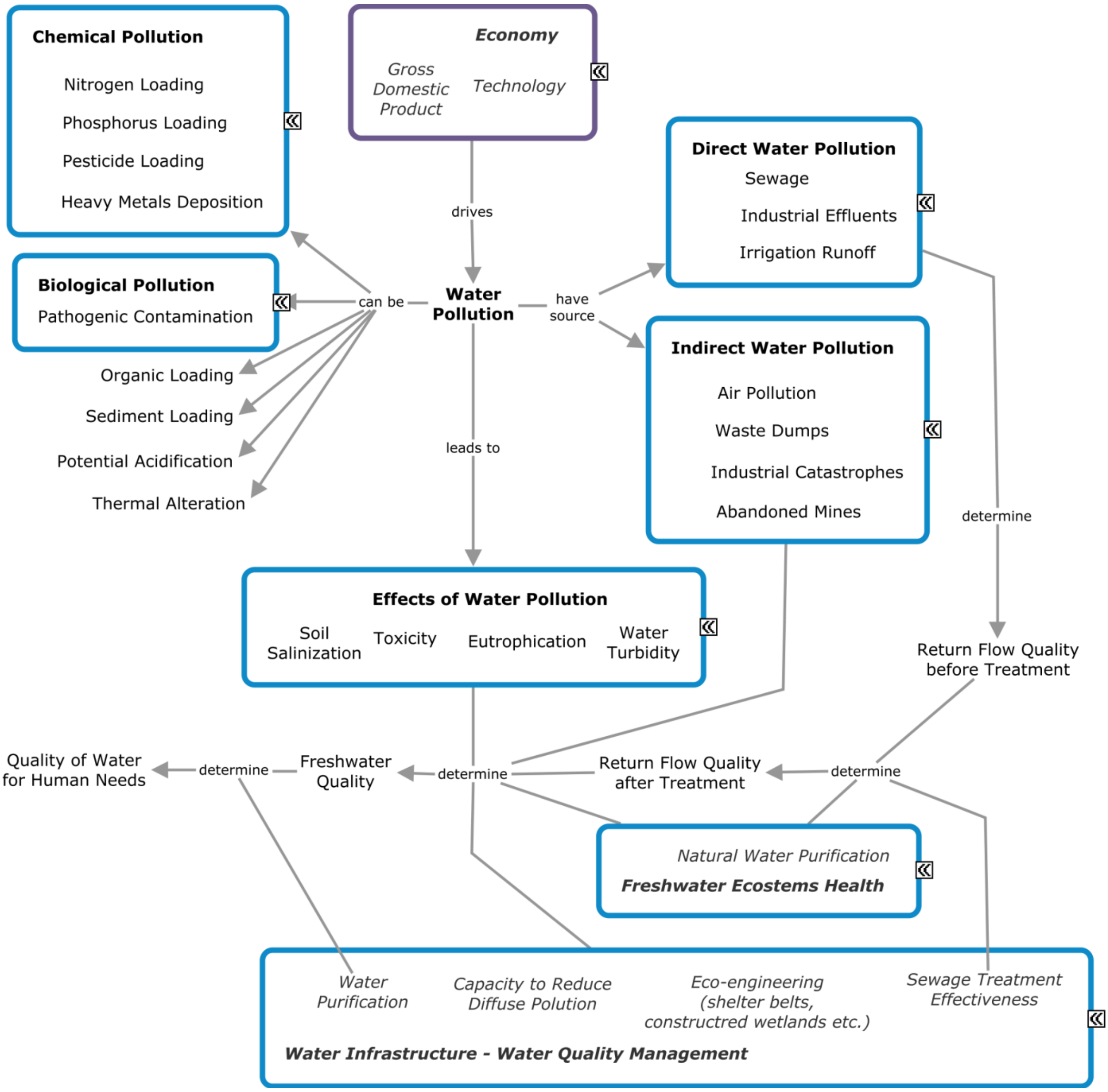

Figure 12. Determinants of water quality.

9 River and Catchment Disturbance

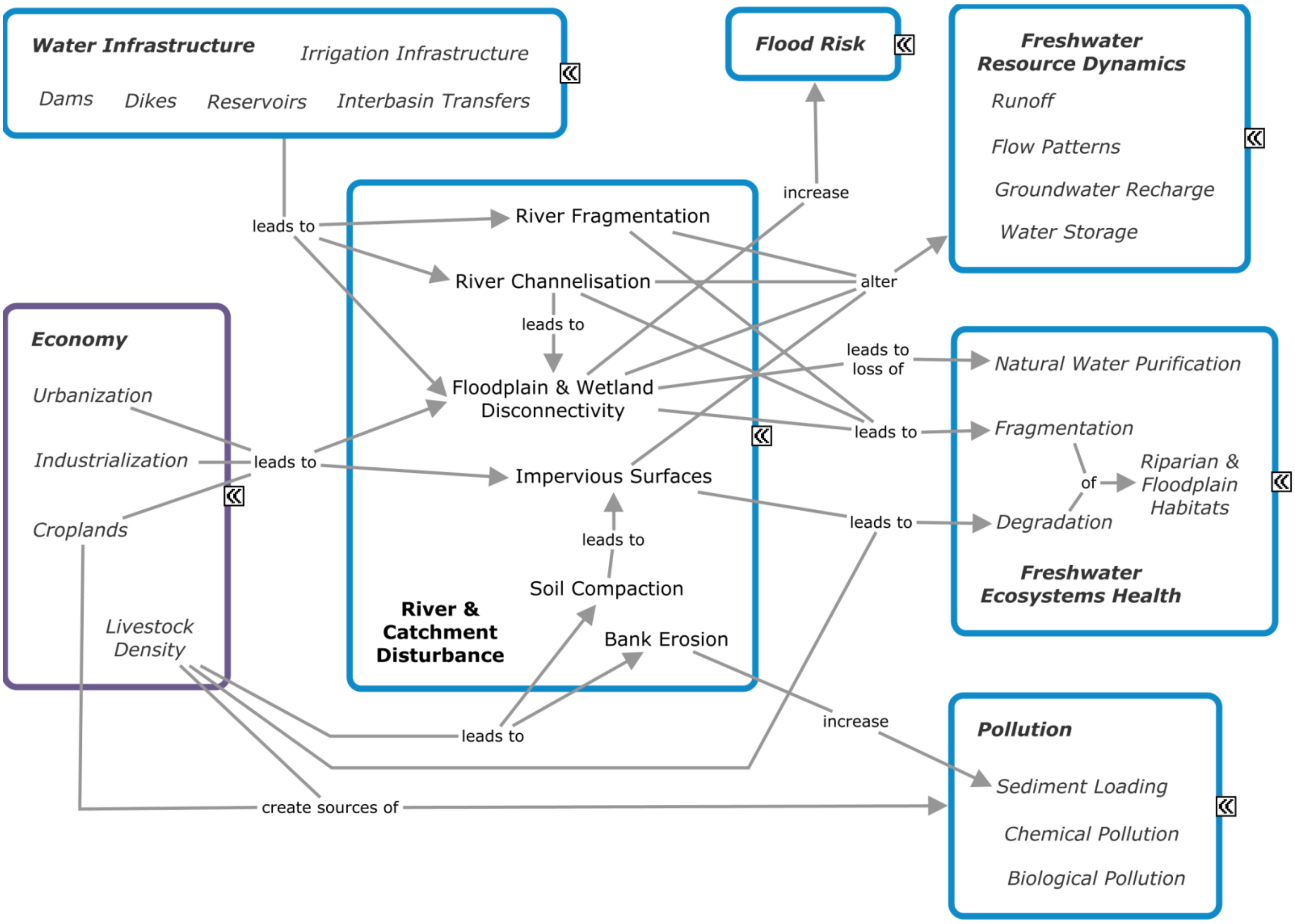

Figure 13. River and Catchment Disturbance.

10 Water Infrastructure

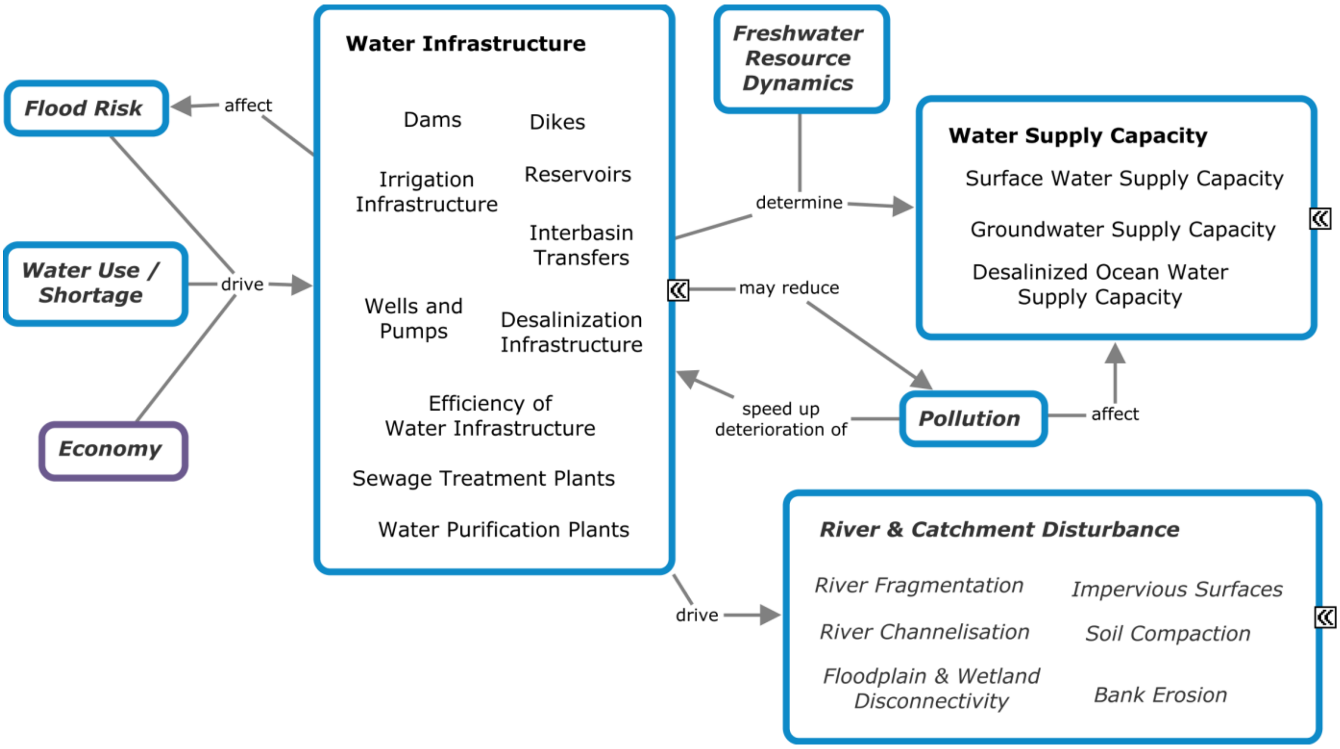

Figure 14. Water Infrastructure.

11 Summary

Diverse conceptual models are regularly developed and used as a means transparently to simplify and generalize key features of the complex realities. Such models allow practitioners to thoughtfully communicate, deliberate over, and decide amid the uncertainty of a changing world. Conceptual modelling can be done with graphic tools such as diagrams, rich pictures, mind maps. They open the discussion of complex systems to include people who find verbal descriptions too long and complicated. Often a single model replaces pages of text required to describe all of the variables and their interactions. Systems thinking methodologies provide easily accessible graphic languages. These languages enable us carefully and transparently to develop mutual understanding between scientists representing different disciplines as well stakeholders from very diverse backgrounds, spanning policy, science, business and local practice, and forge these diverse experiences and perspectives into a common conceptual model or family of models. In cases where in-depth knowledge about relationships between systems elements is available, quantitative models can be built to explore the possible future scenarios in a more rigorous way.

The conceptual framework described in this report has been developed to describe the critical dimensions of water scenarios and relationships between them. It is used both by the scientists in project group and stakeholders engaged to support scenario development. It fosters common understanding and clarity of goals.

The framework is evolving together with new understanding and updated targets. It is stored digitally in a form that is open to expansion and modification.

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