System Dynamics Model to Study the Effect of Different Policies on Bahrain's Hydrological Processes

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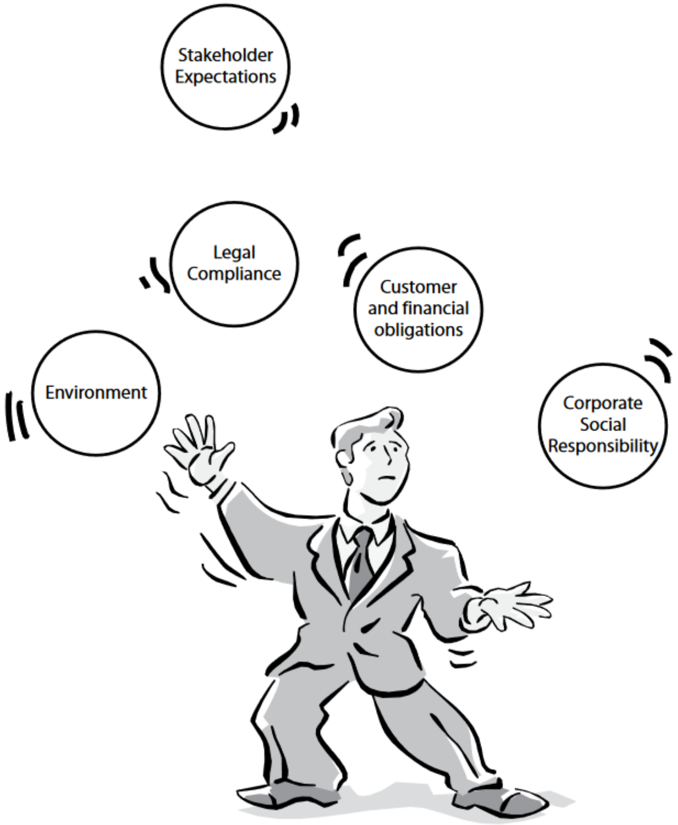
Contents

Introduction and Overview

- Integrated Water Resources Management, Water-Energy-Food Nexus, etc. are all concepts that involve expanding the scope of study to include various relevant sectors
- This involves strong stakeholder communication, conflict-of-interest management, decision-makers' involvement, and communicating highly technical information to laypersons.
- One of the technical tools that helps achieve IWRM in its true essence is <u>system dynamics modeling</u>.
    - Model cross-sectoral dynamics
    - Include correct mathematical representation of the system dynamics
    - Felxiblity to model both qualitative and quantitative inputs.
    - Etc.



Source: AWWA Report

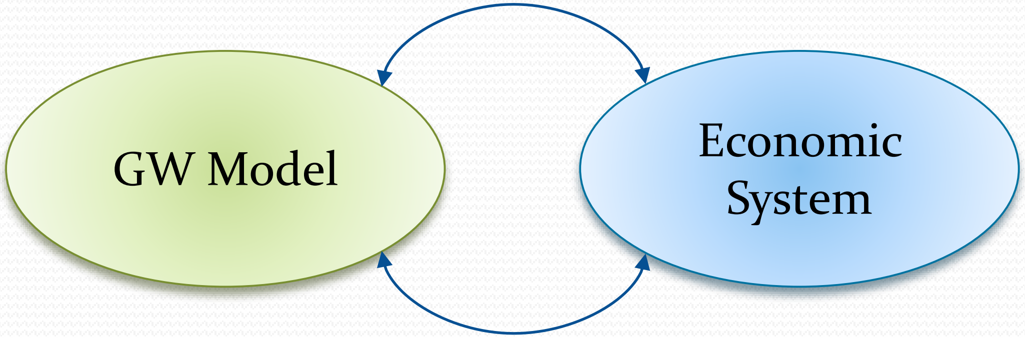
Problem Description

- Beginning in the early 1970s, Bahrain, alongside other Gulf States, has witnessed a significant escalation in developmental progress, hence overexploitation of the main water source: groundwater.
- This economic boom has precipitated a dramatic increase in Bahrain's population, which grew from 0.2 million in 1970 to 1.46 million in 2021
- Intensive groundwater use has significantly decreased potentiometric levels and altered the pressure gradients between the aquifer's relatively fresh water and the neighboring brackish and saline water bodies: leading to sea-water intrusion

Can Bahrain's GW resources be revived?

GW Model

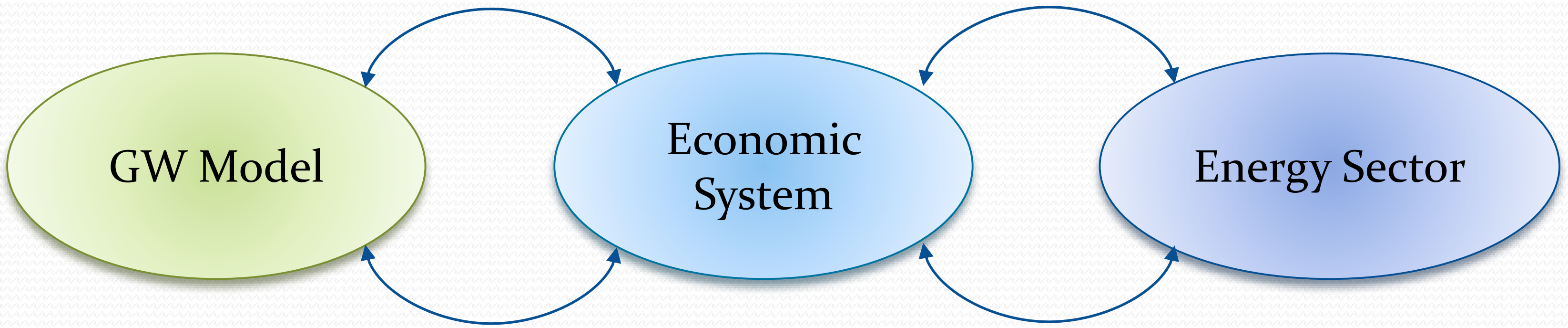
Can Bahrain's GW resources be revived?



Is it financially viable?

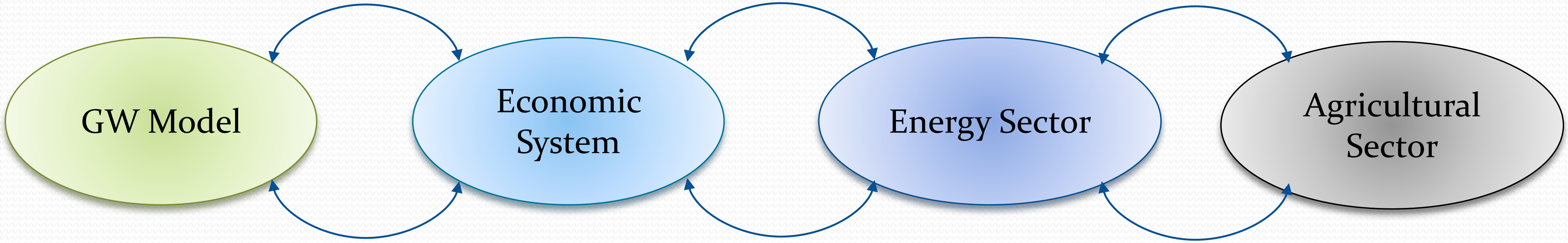
Can we achieve a return on investment through tax schemes?

Can Bahrain’s GW resources be revived?



Would it help reduce energy consumption for water production?

Can Bahrain’s GW resources be revived?



Would it help reduce energy consumption for water production?
Can it be used for irrigation, industrial demand, domestic demand?

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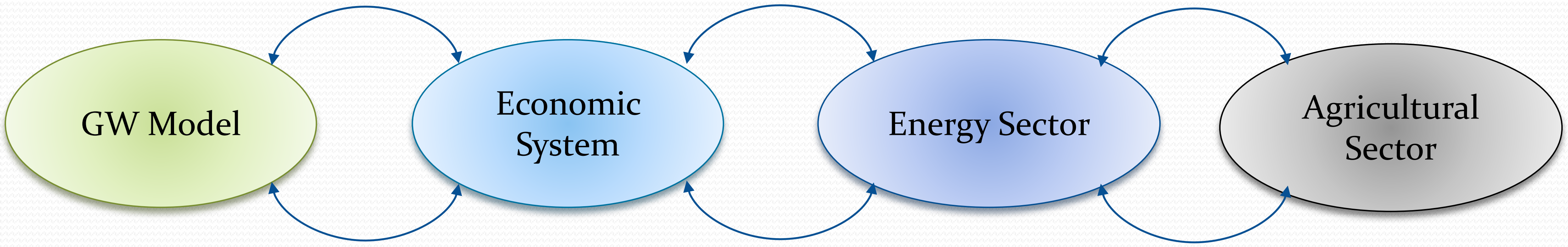


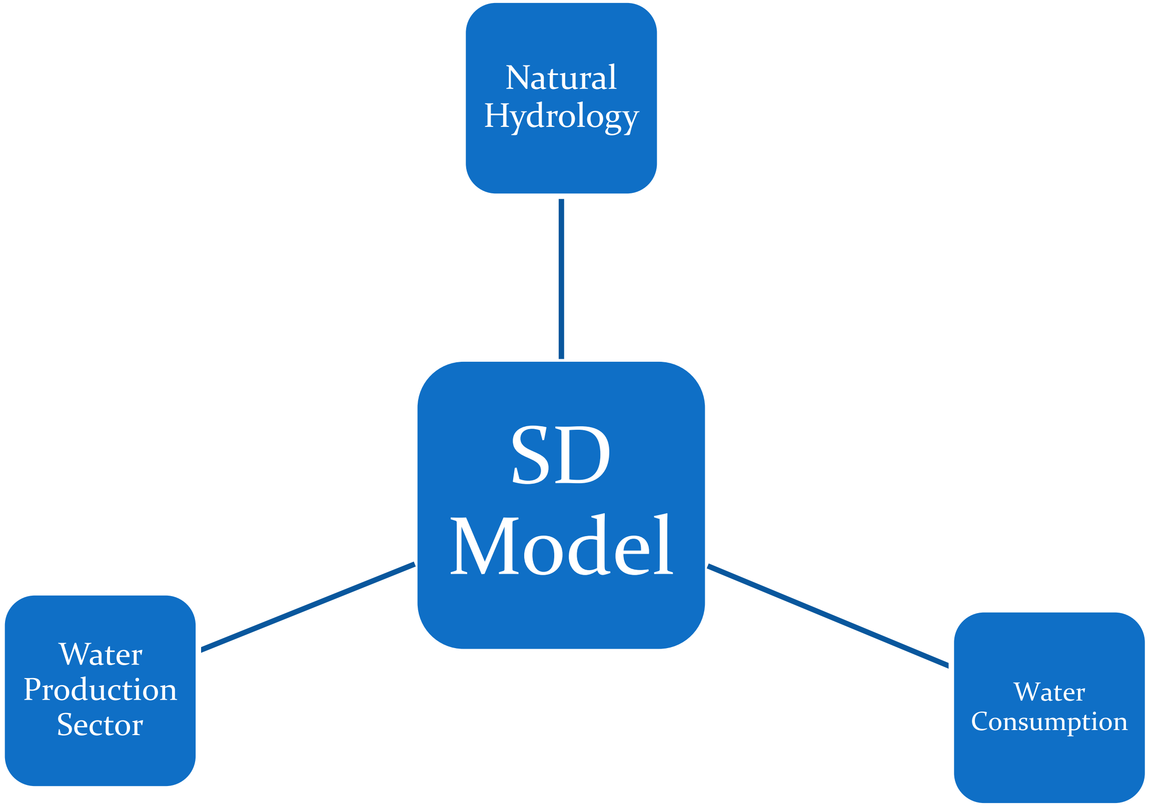
Would it help reduce energy consumption for water production?
Can it be used for irrigation, industrial demand, domestic demand?

And many more …

System Dynamics Modeling

- Define the problem and establish a verbal conceptualization, forming a dynamic hypothesis that explains the issue using causal loops and stock-flow structures.
- Construct an initial causal loop diagram based on this verbal model: A Thinking Model
- Expand the causal loop diagrams into detailed system dynamics flow diagrams.
- Convert these flow diagrams into a computational model using tools like STELLA, VENSIM, or a set of differential or difference equations.
- Determine the parameters of the model.
- Conduct validation checks on the model, assess its sensitivity, and evaluate potential policy implications.

System Dynamics Model (contd.)



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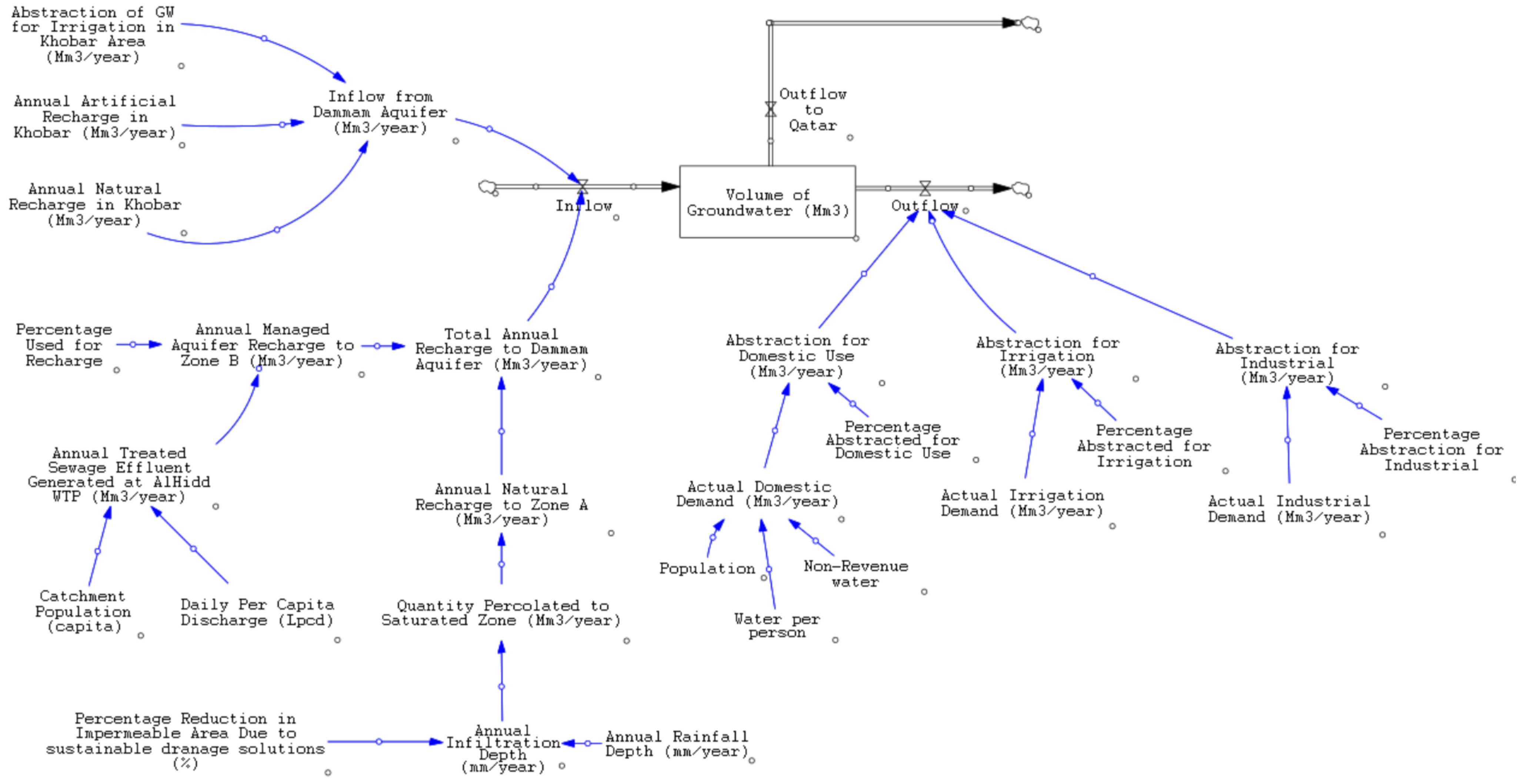
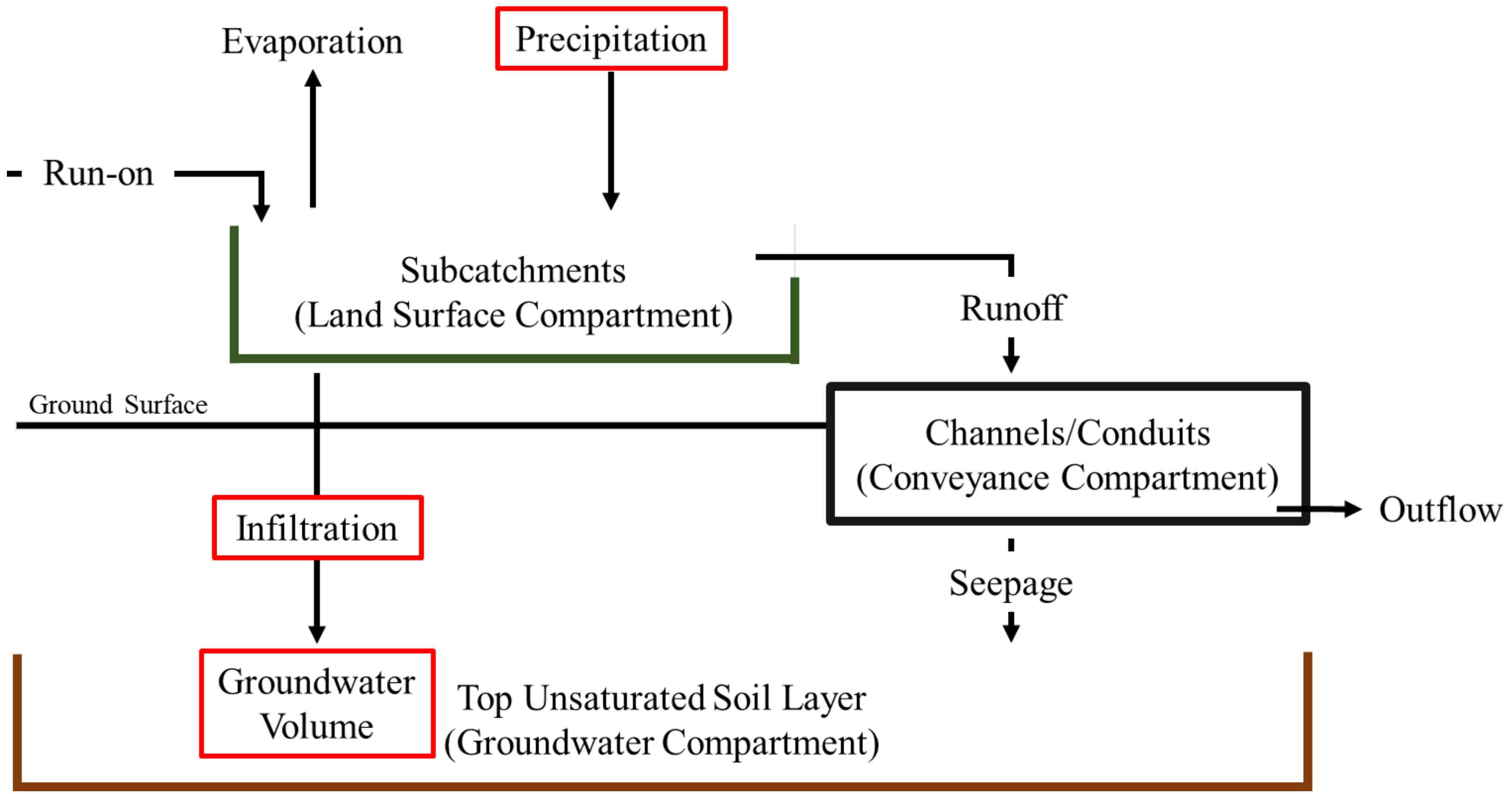
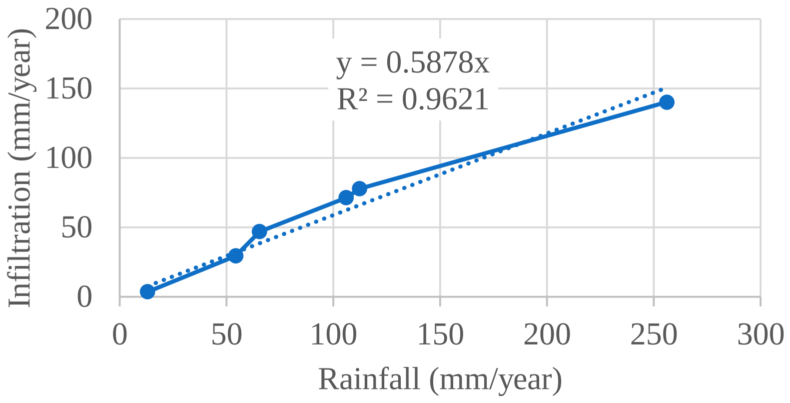
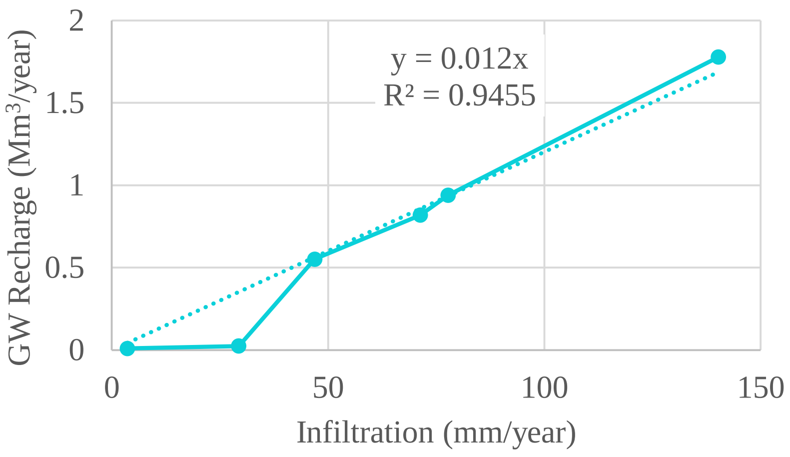


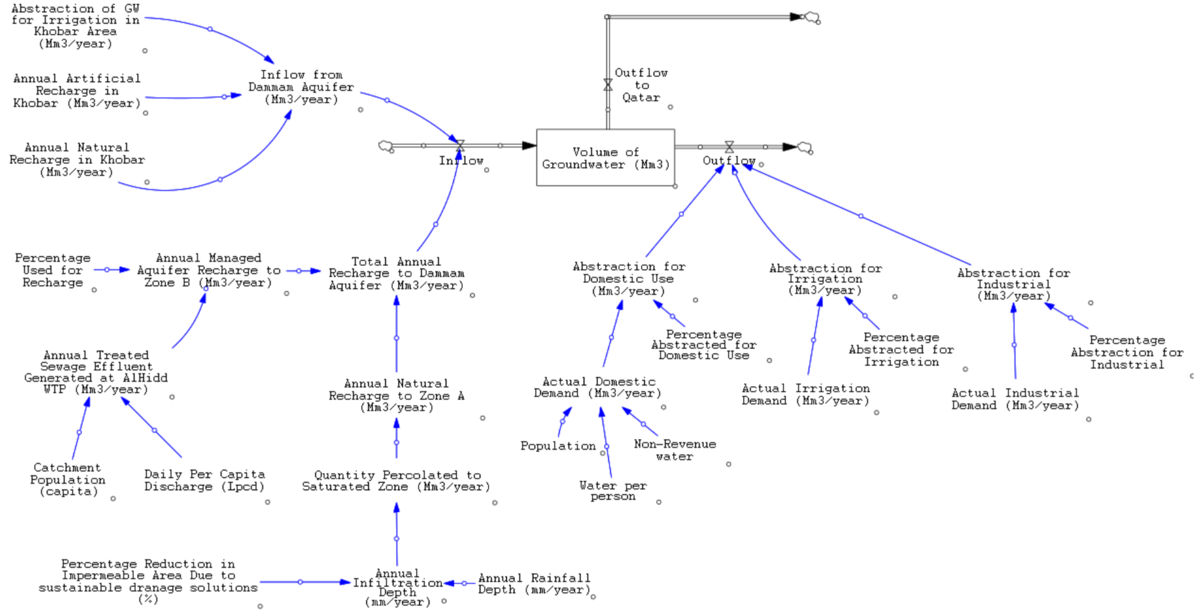
The Hydrological Model: PCSWMM



The Hydrological Model (contd.)





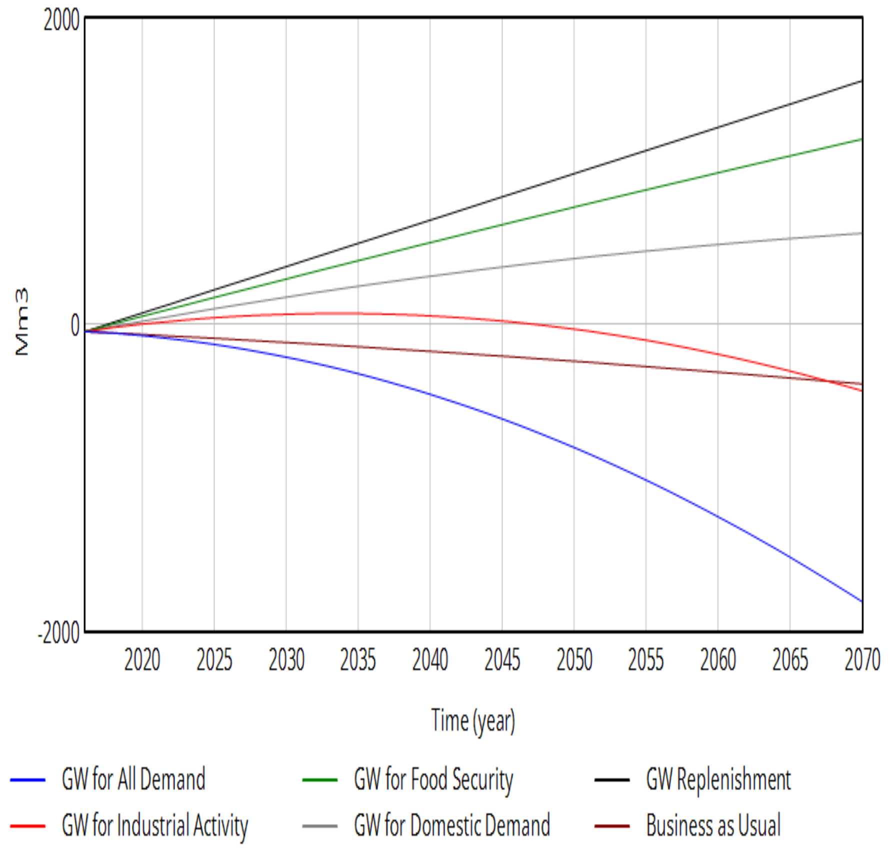


Data

- Observed population and water demand data are obtained from the Bahrain Open Data Portal
- Observed rainfall data are obtained from the Meteorology Directorate
- Future bias-corrected rainfall projections until the year 2070 are obtained from a regional climate model

Results

- Scenarios studied:
  - Business as Usual (Scenario 1) shows a steady decline in GW levels, reflecting the unsustainable nature of current practices
  - GW Replenishment (Scenario 2) maintains a stable GW level, indicating that the injection of 30 Mm^3 annually could offset abstraction, thereby preserving GW reserves.
  - GW for Domestic Demand (Scenario 3) depicts a slight decline in GW levels
  - GW for Food Security (Scenario 4) shows a significant increase in GW levels
  - GW for Industrial Activity (Scenario 5) illustrates a moderate decline in GW levels
  - GW for All Demand (Scenario 6), remarkably, shows a downward trajectory, surpassing all other scenarios by 2070.



Conclusions and Future Work

- This study has presented a comprehensive System Dynamics (SD) model to evaluate the effect of various groundwater management policies on Bahrain's groundwater resource
- The model indicates that replenishment efforts are vital across all scenarios to sustain GW levels.
- The scenarios explored—from the continuation of unregulated groundwater abstraction to strategic replenishment and demand-specific abstractions—highlight the delicate balance required to sustain water resources.
- Our results suggest that, while replenishment efforts can stabilize groundwater levels to some degree, the 'Business as Usual' approach may lead to unsustainable depletion of groundwater reserves.
- Moreover, the more optimistic scenarios may require further validation to ensure their feasibility and sustainability given the physical limits of groundwater recharge (i.e. capping at a maximum or preventing negative values).

Conclusions and Future Work (contd.)

- Enhance the model by incorporating the impact of socio-economic development on water demand and supply. This will include an examination of population growth, economic expansion, and policy changes on groundwater use.
- Investigate the impact of taxing groundwater abstraction in the industrial sector and the potential effects of expanding this sector within Bahrain.
- Develop guidelines for policy implementation that consider the SD model's outcomes.
- Work with local stakeholders, including policymakers, water authorities, and the community, to ensure the model reflects real-world constraints and opportunities.
- Explore the potential for cross-sectoral water management strategies that combine domestic, agricultural, and industrial needs, aiming for a holistic approach to water resource management.