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A System Dynamics Model Approach to Scalable Shared Vision Planning: The Tigris-Euphrates Watershed

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Abstract: Improving the quality of watershed resource management decisions by regional stakeholders, the U.S. Government (USG) interagency, and international investors represents an important capability in addressing increasingly complex global water security challenges. This research presents a scalable 'Shared Vision Planning' (SVP) framework which integrates methods from the fields of System Dynamics with Decision Analysis through visual aids to enhance evaluation of watershed solutions while reducing cognitive load on decision makers. The framework is meant to elevate insights about dynamic attribute tradeoffs and sensitivities such as hydro-power yield, water storage, agricultural yield, and flood risk mitigation. Findings of this research were presented to USACE IWR senior leadership thus confirming initial research aims of framework and interface designs; follow-on beta testing to examine cognitive loads represents follow on research to be performed with USG interagency practitioners and leadership. The Tigris-Euphrates watershed served as the initial proxy for examining efficacy of the SVP framework.

Keywords: System Dynamics, Decision Analysis, Shared Vision Planning

1. Introduction and Background

The Tigris-Euphrates (T-E) watershed represents a dynamic watershed facing a myriad of challenges, including population growth, climate change, geopolitical conflict, and a severe refugee crisis (Akanda, 2007). These challenges pose a significant threat to the region's water security, which is vital to sustaining population and enabling economic development; this motivation was more broadly captured in the USACE IWR-Future Directions Report of 23 Sept 2016 on 'Enhancing International Water Security'. Projected water shortages in the T-E watershed are likely to increase tensions between Turkey, Syria, Iraq, and Iran, further deteriorating the political climate in the region (Beaumont, 1998). Strain on the populations who rely on the T-E water supply to irrigate crops and produce clean drinking water potentially could contribute to the current or future refugee crises (Wilson, 2012). Furthermore, deteriorating water resource issues, paired with the lack of multilateral water-sharing agreements in the region, pose a significant threat to U.S. national security interests (National Intelligence Council, 2012). It is increasingly apparent that the USG interagency must embrace regional water security as a stabilizing force and grow organizational capacity to facilitate quality decisions regarding watershed resources.

The re-defined problem statement illuminates the significant challenges given the lack of a standardized decision framework and visual aid designs to help improve watershed management decision quality towards improving regional water security. There exists an immediate need for a value-focused, scalable SVP framework and visual tool design to aid USG interagency practitioners in facilitating regional stakeholder watershed understanding and improving the quality of decision making. The methodology will describe a prototype framework and its internal models used to assist in SVP for the T-E watershed, but scalable to address all other watersheds facing water security challenges both internal and external to the United States.

2. Methodology

The USACE is interested in developing a scalable SVP for use by the USG interagency to address overseas water security issues. SVP is a process that facilitates cooperation between multiple stakeholder entities, links technical experts and policy makers, and generates improved understanding to inform decision making; it has been applied overseas in Peru and China (Chang, Mendoza, and Ligh, 2015). The general process has also been applied in the continental U.S. in the Potomac River and Great Lakes watersheds (Bourget, 2011). Each SVP effort has varied in the framework chosen and time to complete based on maturity of the region and capacity of those involved in the effort. Levels of technology used to highlight watershed system attribute performance have also varied and no one standard scalable framework or interface is in use (Olszewski, 2018).

A scalable SVP framework was developed and consists of four components: receive input from stakeholders, develop candidate solutions, model candidate solutions, and produce value score and make a decision. The framework in Figure 1 was heavily influenced by the Systems Decision Process (Parnell, Driscoll, & Henderson, 2011) and themes captured from multiple IWR and HQUSACE interviews with practitioners and senior leaders held on 16/17 October 2017 and 21 February 2018. Timeline to implement the framework would vary based on the availability and capacity of the stakeholders involved; interviews revealed that a heuristic of four, four-hour long formal sessions to work through each phase would be a prudent planning factor (Olszewski, 2018).

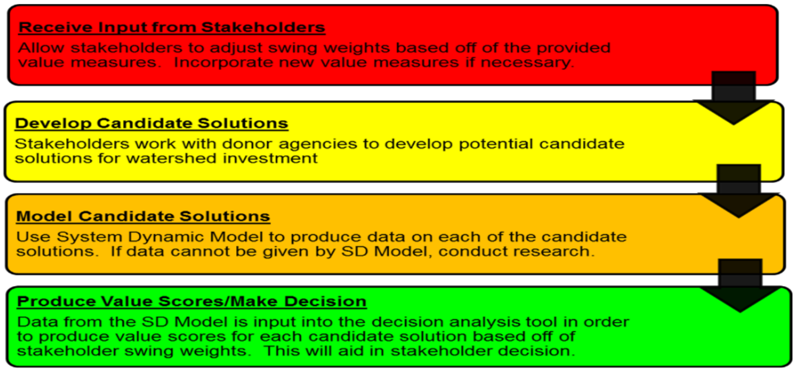


Figure 1. Shared Vision Planning (SVP) Framework

2.1 Receive Inputs from Stakeholders (Framework Step 1)

2.1.1 Conduct Research and Stakeholder Analysis

A series of interviews with USACE IWR practitioners involved in current SVP-like efforts revealed that water supply is critical because it directly influences irrigation, hydropower, and public health. In addition, a literature review revealed a series of environmental themes to consider including but limited to climate change, population growth, water usage, and water security (Chang, Mendoza, and Ligh, 2015). It was determined using a 'Findings-Conclusions-Recommendations' methodology of stakeholder and literature review information that the anticipated effects of climate change were negligible when compared to those of population growth, water usage, and security, and for this reason, it is not included in the first version of the System Dynamics model to be described in this paper.

Application of this 'red' framework phase in Figure 1 would be customized to the number of stakeholders involved, the time available and the political sensitivities of the region. Consideration about who to include in these initial interviews or focus groups would need to take into account their knowledge and perspective about the watershed in order to enhance shared situational awareness across multiple stakeholders.

2.1.2 A Scalable Qualitative Value Modeling

A value-focused thinking approach was employed to identify important factors in watershed management, and these were used to calculate value scores. The qualitative value model displayed in Figure 2 shows the objective function for the decision tool, as well as the functions, objectives, value measures (Parnell et al., 2011) and a set of pre-constructed 'add-ins' for stakeholders to scale their unique value model. In discussions with IWR practitioners, the 'add-ins' in the value model were identified as essential in ensuring regional stakeholders attained true ownership of the model. The team identified the fundamental objective as improving water security in the Tigris-Euphrates watershed (National Intelligence Council, 2012). Based off of SVP methodologies developed by Chang, Mendoza and Ligh (2015), the three primary functions to achieve the objective function are provide economic opportunity, enhance social factors, and mitigate environmental risks. A baseline value model for stakeholders was created to represent common functions that most all watersheds would need to consider. The stakeholders would then utilize the scalable 'add-ins' to create and customize a value model specific to their watershed in order to ensure their regional values are incorporated in the SVP tool; these items will continue to be developed during beta testing.

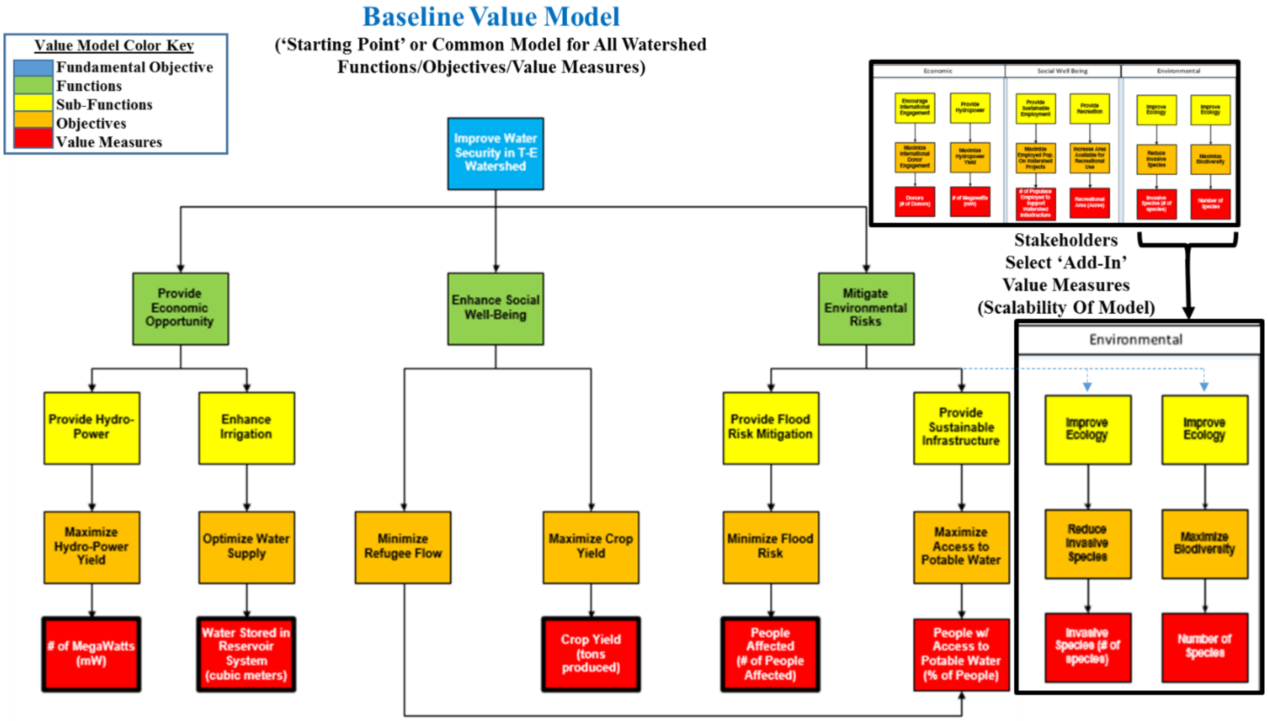


Figure 2. Scalable Value Hierarchy for the T-E Watershed

2.1.3 Quantitative Value Modeling

Swing weights were interpreted from stakeholder discussions at USACE IWR for the T-E proof of concept, but in application would be derived using a swing weight matrix and assessments from actual regional state actors. The global weights (Equation 1) for the swing weights indicate the value measures' relative importance compared to each other (Parnell et al., 2011).

In order to score each course of action, value functions are also needed for each value measure. Value functions convert raw data from a system dynamics model or other scoring model into scaled value scores which can be used to calculate total value scores. Regional stakeholders would be required to assess value functions using the technique assigning residual return-to-scale values at 25%, 50% and 75% against a raw score range.

$$Global\ Weight = \frac{Swing\ Weight}{\sum Swing\ Weights} \tag{1}$$

$$Total\ System\ Value\ Score = \sum (Scaled\ Value\ Score)(Global\ Weight) \tag{2}$$

The total of each individual value score is calculated by multiplying the scaled value scores for each value measure by their global weights to find weighted value scores. The sum of the weighted individual value scores (Equation 2) for each candidate solution yields the total system value score (Parnell et al., 2011).

2.2 Developing and Modeling Candidate Solutions (Framework Step 2 through 4)

2.2.1 Developing the Candidate Solutions

Three candidate solutions were developed for beta testing of the system dynamics model; these candidate solutions were derived from multiple articles describing investment opportunities across the watershed. The first included construction of a new hydropower dam on the Tigris River near Baghdad. The second described a major diversion from the Tigris south of Mosul to provide irrigation to rural farmers. The third included construction of a new hydropower dam on the Euphrates River, north of Ramadi (Melikoglu, 2017) in order to allow Ramadi to be more self-sustaining and have more water control (Shared Tributaries, 2018).

2.2.1 Modeling and Scoring using a System Dynamics Model

The system dynamics model is represented in the form of a Stock and Flow diagram and is designed to test total watershed system performance about how the entire watershed system might be utilized to ensure successful water sharing policies (Al-Ansari, 2015). The System Dynamics Model allows for the scoring of the value model's value measures; the parametric models underlying the model are shown in Equations 3 through 6. Stocks indicate current and future dams and are then surrounded by three major flows: inflow, outflow, and dam carrying capacity. Flows represent how much water is running through the watershed at that location at a given time. The dams are represented throughout the entire watershed and the outflows represent the water discharge flow rate leaving that specific area and is measured in cubic meters per second (Daggupati, et al., 2017). Data was collected using the annual average discharge rate from 1926-2004 at each given location represented in the model (The World Bank, 2018). The hydropower model is a direct pull from the World Bank Group and crop yield derived from multiple sources.

The T-E model for this proof of concept is illustrated in Figure 3 with a blow-up of one section of the model using Vensim, which is a simulation software that improves the performance of real systems by assessing stocks and flows. Overall, the model allows stakeholders to visualize the results of candidate solutions along the T-E watershed based on the demand from the population of specific areas. The complete model consists of a string of these individual portions and represents the physical layout of the T-E watershed from north to south.

$$Outflow = (Inflow) - (Tank\ Capacity\ Demand \tag{3}$$

$$Dam\ Flow\ Rate = (Inflow) - (Tank\ Capacity\ Demand - Outflow) \tag{4}$$

$$Crop\ Yield = \frac{(water\ available\ for\ irrigation)*(crop\ production\ per\ acre)}{(water\ required\ per\ acre)} \tag{5}$$

$$Hydropower\ (P) = (9.81\frac{KN}{m^2})(Dam\ Flow\ Rate)(Head)(Efficiency) \tag{6}$$

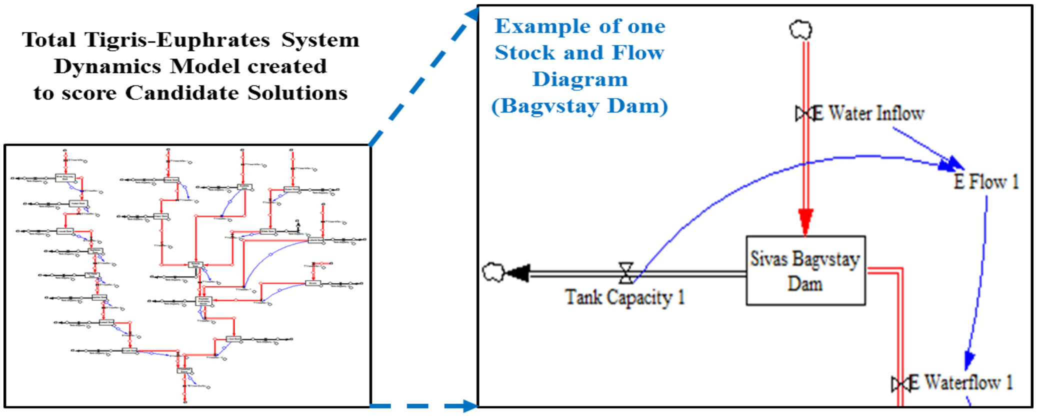


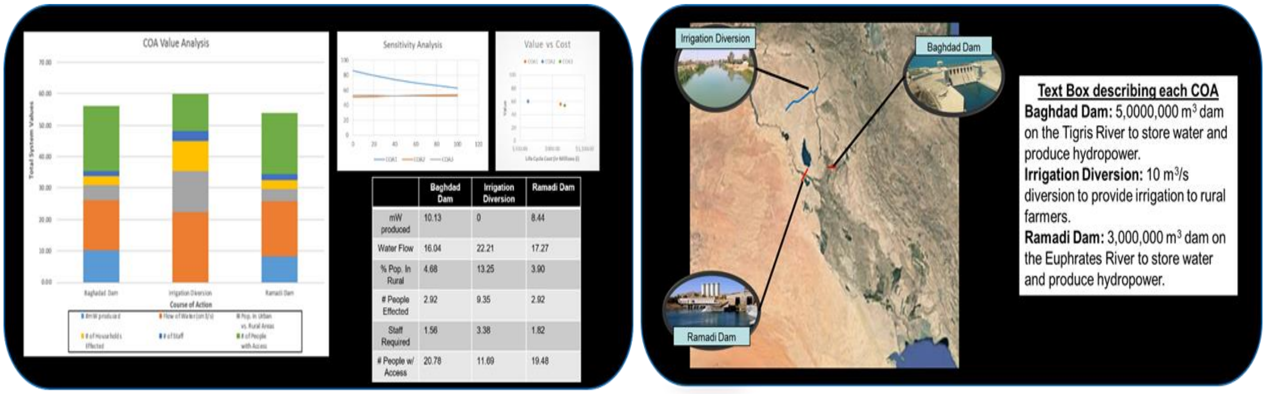
Figure 3. Stock and flow diagram of the Tigris-Euphrates watershed

Using the system dynamics model described in Figure 3, each of these candidate solutions were tested and scored. The data produced was then used to calculate total system value scores using stakeholder-determined value functions normalized scores using Equation 2.

3. Shared Vision Planning Interface Prototype Design

Once the total system value scores have been calculated for each candidate solution, results were displayed using SVP interface tools. The first of these products was a stacked bar chart, such as the one displayed in Figure 4. The stacked bar chart shows the stakeholder the total system value score for each candidate solution; the breakdown of each value measure is displayed in color illustrating tradeoffs and opportunities for improved candidate solutions.

The next interface tool that is produced is a sensitivity analysis. The sensitivity graph display the effect that variation in swing weights has on total value scores. If the total value scores are too sensitive to manipulation of a swing weight, this might decrease the level of confidence that stakeholders have regarding which candidate solution truly holds the greatest value. However, if the total value scores are not sensitive, stakeholders would be able to be confident in the results; each value measure would be able to be displayed on the interface as selected.



	Baghdad Dam	Irrigation Diversion	Ramadi Dam
mW produced	10.13	0	8.44
Water Flow	16.04	22.21	17.27
% Pop. In Rural	4.68	13.25	3.90
# People Effected	2.92	9.35	2.92
Staff Required	1.56	3.38	1.82
# People w/ Access	20.78	11.69	19.48

Text Box describing each COA

Baghdad Dam: 5,0000,000 m^3 dam on the Tigris River to store water and produce hydropower.

Irrigation Diversion: 10 m^3/s diversion to provide irrigation to rural farmers.

Ramadi Dam: 3,000,000 m^3 dam on the Euphrates River to store water and produce hydropower.

Figure 4. Prototype Shared Vision Planning decision interface

The third interface tool is a cost vs. value analysis graph. This graph plots the total value score of each candidate solution in relation to its cost. This allows the stakeholders to see how much a candidate solution would cost relative to the value it provides, enabling cost-benefit analyses to occur. Estimates for the three fictional candidate solutions were developed using a historic, top-down driven cost estimation. If time is available, a parametric or bottom-up cost estimation of each candidate solution would be preferred.

Together, these interface tools enable stakeholders to visually understand the tradeoffs of each candidate solution. Interface design features addressing proximity compatibility of items and focused attention of the decision maker (Wickens, Hollands, Banbury, &, Parasuraman 2015) were engineering design features considered in developing this initial prototype and received positive anecdotal results, but would need to be further examined for impact in reducing cognitive load.

4. Conclusions

In order to improve water security in the Tigris-Euphrates watershed, the team has developed a scalable SVP framework which leverages basic approaches and principles from the fields of System Dynamics, Decision Analysis, and Engineering Psychology, yet there is much research to be completed. The overall SVP framework will continue to be revised for future use as this work represents a 'next step' in formalizing current and previous efforts. This framework adopts the 'value creation' approach and could be enhanced in further iterations with risk-based decision making methods. The interface could be enhanced through robust testing of multiple designs using eye-tracking software and survey instruments would be able to assist in understanding the reduction on overall cognitive load.

Furthermore, the system dynamics model is employed to score each of the candidate solutions and represents an essential first technical step before engaging stakeholders in interviews under step 1 of the framework, however much work could improve this scoring model. Additional layers should be integrated into the model to ensure that it sufficiently outputs data for each value measure to include every 'add-in' value measure. This includes recommendations to layer flood risk GIS modeling parametric equations which account for seasonal patterns in hydrology. In addition, the development of a parametric model to capture climate change in the region would assist in better understanding the watershed dynamics and potentially help in assessment of correlations to refugee migration patterns. Future iterations of the System Dynamics model within the SVP framework should continue to undergo iterative design validation with practitioners such as IWR and other willing USG interagency partners.

The scalable SVP framework described in this paper will enable the USG interagency to facilitate improved understanding of watershed decisions with leaders around the globe thus leading to enhanced international cooperation, improved water resource management, and greater stability in regions threatened by water security.

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