Community Engagement in Water Resources Planning Using Serious Gaming

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Abstract—**The necessity to optimize the use of water resources and to raise the awareness of different categories of stakeholders to competing user demands requires development of systems analyses involving big data situations. The paper presents a virtual problem-solving environment aimed at engaging individual citizens and communities in decision making using a game-like approach. A web-based environment was developed and successfully used for delivering the game into the community. The web-platform entailed the technical aspects of the multi-hazard mitigation planning (including visualization of the selected scenarios) as well as the mechanics of the game delivery (instructions for platform usage, compilation of scores, etc).**

Keywords — Decision Support Systems; Community Engagement; Serious Gaming, Hazard Mitigation, Risk Assessment

I. INTRODUCTION

The statement that water resources are inevitable and irreversible harmed by people living in watersheds is widely accepted. The considerable growth of population and human intervention within the watersheds in the last half century, have transformed the harms to natural resources into threats (hazards) to socio-economic landscape under the form of floods, droughts, accelerated soil erosion, and critical depletion of the oxygen in water bodies. Pressed by the continuous human losses and economic burden associated with hazards, local and international communities of practice warn on the detrimental impacts of natural hazards, irrespective of their type, and on the necessity of acting immediately and planning accordingly for the future. Among the many obstacles for immediate action in mitigating multiple hazards, the water resources management communities are well-aware of two major ones, as briefly summarized below.

First, is the vast amounts of un-coordinated funds spent in many national and international watersheds at the local and state levels to address multi-faceted water resources hazards. Solutions to these issues are typically formulated from a sectoral perspective (e.g., assuring water for various uses, mitigating flood, stream water quality or aquatic habitat) without coordination at the watershed scale. Often times, stakeholders are working to solve issues in isolation according to their personal interests or mission. This singular interest perspective poses difficult choices on assessing benefits and/or costs across jurisdictional boundaries (e.g., the upstream/ downstream flood mitigation dilemma). Continuously increasing of watershed stresses due to land use and climate changes at a time when public funding for addressing water resources-related concerns is declining requires promotion of integrated and comprehensive planning. Such ambitious planning approach must include participation and actions of all individuals and groups with interests in the vitality of the watersheds. There is a vast amount of publications that refers to a wide variety of benefits that are gained through the participation of stakeholders in research and decision-making [1]. The advent of web-based supporting tools and the wide introduction and acceptance of the social media and other web applications have considerably augmented the participatory experiences leading to new terms for this participation, i.e., collaborative modeling (e.g. [2]) or participatory modeling (e.g. [3]).

Second, a growing number of actors in the watershed decision-making have recognized that technical solutions do not always perform well in mitigating sustainability and adaptability strategies for practical situations, as science does not automatically translate to practice, because of the various perceptions (e.g. [4]) and interests of the stakeholders (e.g. [5]). Efforts are currently invested to enhance collaborative decision-making in the watersheds, by developing the "enabling technology" for formulating sound, cost-effective, and timely solutions to water issues [6]. Among these efforts are those focused on rigorous development of comprehensive integrated information systems geared to the management of natural resources [7]. Examples of emerging large-scale digital databases and services include those developed by the Consortium of Universities for the Advancement of Hydrologic Science's (CUAHSI) Hydrologic Information System [8], Hydroshare [9], and the Community Hydrologic Modeling Platform [10] as well as smaller-scale digital hubs for dissemination of information (e.g. [11], [12]).

These initial efforts can serve as models for common infrastructure development entailing community-supported watershed databases and analyses systems for actual integrated water resources management. These efforts usefully bridge science and practice in order to produce actionable scientific knowledge that meet the criteria of the scientific community and the requirements of the water management practitioners [2]. Among the technological innovation are the "collaborative" technologies as implemented in are serious gaming [3] where stakeholders play active role in the decision making trough engaging role-playing games. This paper presents the essential cyberinfrastructure associated with the organization of a multi-hazard "tournament" (MHT) using a serious-gaming alternative [13]. The MHT as presented herein is one of the possible paths to engage the community in the planning process by hiding the complexity of the technical aspects and providing a problem-solving environment that is understandable and adapted to the technical skills of the local watershed stakeholders. The MHT was proof-tested through an actual competition held in the Midwest US in the Fall of 2015 (see Figure 1). The input received from the tournament participants following the game delivery was encouraging, validating both the general game-based concept as well as the details of its delivery.

II. Game Playbook Essentials

The MHT was designed to be delivered in a game-like environment that promotes social learning through teams playing out potential adaptation strategies to reduce drought and flood risk while addressing water quality issues. A decision support system (DSS), dubbed the Iowa Watershed Decision support System (IoWaDSS) was used as the host for the planning activities. The IoWaDSS planning tool aims to provide a general framework for watershed planning and management that includes the necessary data, tools, and to solve complex problems within a watershed of interest. This framework entails seven, sequential steps, wherein stakeholders, decision-makers, and communities may: (i) form groups and set watershed goals and objectives, (ii) explore resources, risks and vulnerabilities of the historical, current, and future climate conditions of the watershed, (iii) identify alternatives and best management practices, (iv) assess alternatives, (v) select a watershed strategy from alternatives, (vi) implement the selected watershed strategy and/or action plan, and (vii) monitor and evaluate the results (Figure 2).

The IoWaDSS planning tool was customized for the MHT to support each team's selection of adaptation strategies and inform decisions. The planning tool provided a serious game framework that guided the players through the MHT game play with the necessary tools, data, and visualizations that could be used by novices or experts from diverse backgrounds in the watershed management sector. It played an integral part in the MHT because the planning tool provided interfaces that took each team's input, and their watershed strategy, and then provided an evaluation of each team's watershed strategy for feedback. The planning tool was designed to be a cost-effective, safe, and timely method to introduce and familiarize stakeholders to the general practices, considerations, constraints, and scenarios typically encountered within the watershed management and planning sector. Described next are the context of the gameplay and the critical role played by the web-based IoWaDSS portion designed for the MHT to make it successful in practically engaging the communities in decisions using a participatory approach [13], [14].

A. *Tournament Actors*

There are four main actors involved in the MHT game – players, referees, team facilitators, and the announcers. The players are part of a team and they use their knowledge and expertise to help their team select adaptation options, communicate the reasoning behind their decisions through press release responses, and assign scores to the other teams. The referees act as content experts by providing consultation, insight, and feedback to competing teams. They evaluate the feasibility of innovative adaptation options and participate in the scoring process. Along with participating as a team player, the team facilitators also track their team's budget, facilitate team discussions, and submit their team's decisions, press release responses, and scores. The announcers present the constraints of each turn, monitor time, and calculate the scores.

Fig. 1. Image from the MHT competetion using the web-platforms developed atop of IoWaDSS.

B. *Gameplay Phasing*

The main role of the IoWaDSS Planning Tool within the MHT was to provide a platform for which players can easily view and select their adaptation options, and analyze the output of their team's scores from the modeling results based on their selection of adaptation options. As a result of displaying the list of pre-defined adaptation options and the spatial distribution of chosen land cover options within the map component, the IoWaDSS planning tool aims to spur conversations and enhance discussions between players. In order for discussions about watershed management strategies occur, the IoWaDSS planning tool must act as a supportive tool, only taking one's attention and time that it absolutely needs for the game play to proceed accordingly so that the players can focus on having discussions with others instead of trying to learn a new interface during the game. Thus, for the interfaces to be of value to the MHT, they must be designed to be accessible, usable, useful, desirable, and credible. The IoWaDSS web-based portal enabled the teams to simultaneously and in real-time choose potential adaptation options as part of their watershed management strategy based on the climatic scenario associated with a particular turn, see Figure 3.

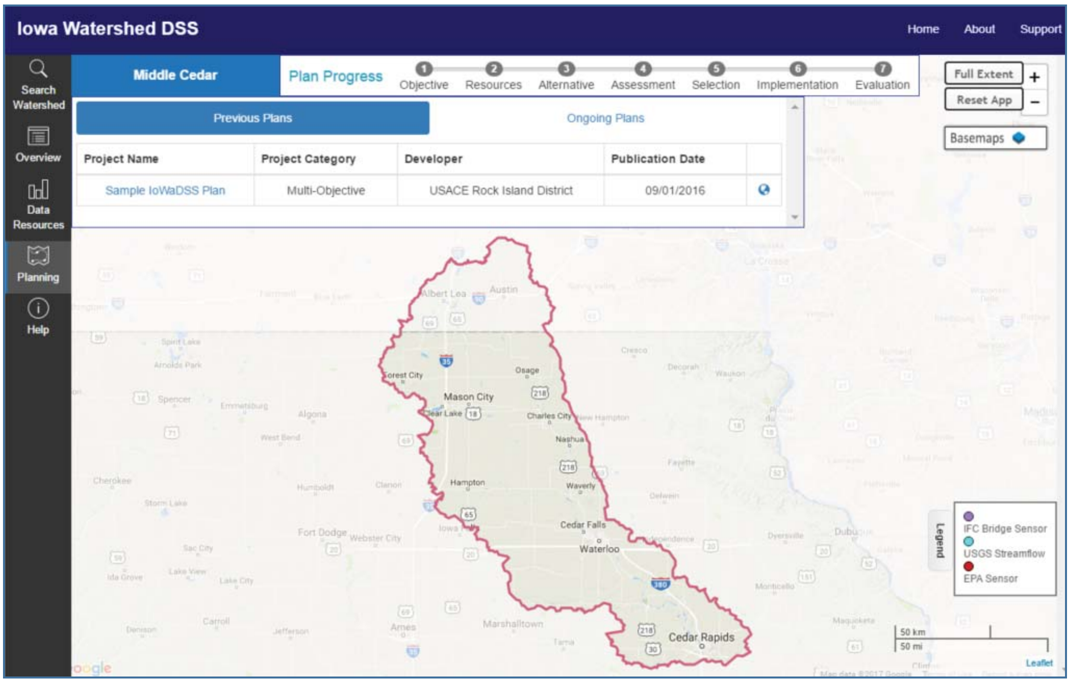

Fig. 2. IoWaDSS user interface for the conduct of planning activities (7 steps)

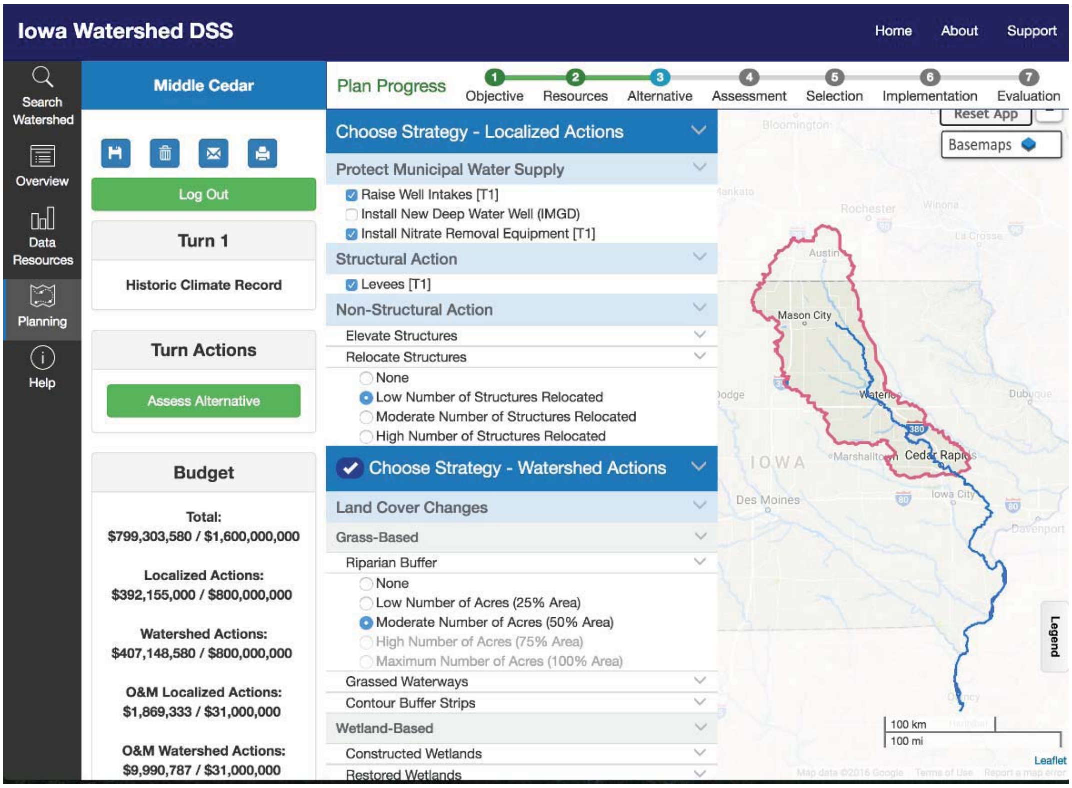

Fig. 3. Customized IoWaDSS interface for the delivery of the Multi-hazard Tournament (steps 1-4)

Turn Scenario Set-Up and Presentation. For each of the four tournament turns, there was a different climate scenario that the teams confronted and accounted for within their adaptation option planning. The first turn represented the historical climate record. Teams used this turn to establish the foundation for their watershed management strategy, using the money allotted them to invest in capital and watershed improvements over a 20 year planning horizon. Teams had the option of choosing structural, and/or non-structural adaptation options that in turn influenced their strategies and budgets for turn 2 (flood scenario) and turn 3 (drought scenario). Turns 2 &3 represented a 1 year planning horizon which had to account for the operation and maintenance costs associated with decisions made in turn 1 in addition to the costs related to new adaptation options. Turn 4 presented a climate change scenario that included more frequent and extreme hazards. For turn 4, the team's watershed management strategy was reset to a 20 year planning horizon so that teams could reinvest their full budget based on the lessons learned in the three previous turns.

Adaptation Option (Solution) Selection. With a limited budget, each team carefully considered budget constraints, tradeoffs, and cost-effectiveness of their plan. The pre-defined adaptation alternatives used in the simulations were selected based on the options currently being used or considered in the Cedar River Basin. The adaptation options included localized alternatives (i.e. protect the municipal water supply, structural actions, non-structural actions) and watershed actions (i.e. land cover change that is either grassland-based, wetland-based, grassland and wetland-based, or land cover and land management change). The information needed to inform each team's selection of pre-defined adaptation options was obtained through an extensive number of computational simulation results that were embedded in the IoWaDSS.

The computational simulation results embedded in the IoWaDSS were obtained from running simulations with eight different multi-domain models (physical and socio-economic). The watershed based simulations used 40 different alternative practice combinations. The input and output data associated with the pre-run simulations were stored in the IoWaDSS relational database along with information on how each of these pre-run simulations, if selected in different combinations by the teams, would interact with each other and ultimately impact the environmental, economic, and social scores. The snapshot of the IoWaDSS interface used by players to choose the adaptation options is provided in Figure 3. It is an interface that allows to select adaptation options, analyze budget, review the operation and maintenance costs for the selected actions, and submit the watershed strategy through the decision support tool. The web-portal allows players to evaluate for each turn how well their adaptation options performed against a pre-established evaluation matrix.

Press Release Presentation. During the press release, the teams presented their proposed solutions and described the rationale for the adaptation options they invested in to prepare for the forecasted climate conditions, why they felt this approach was the most appropriate, and what were the implications in terms of tradeoffs between impacts to the physical landscape as well as tradeoffs between impact on different economic, social, and environmental sectors.

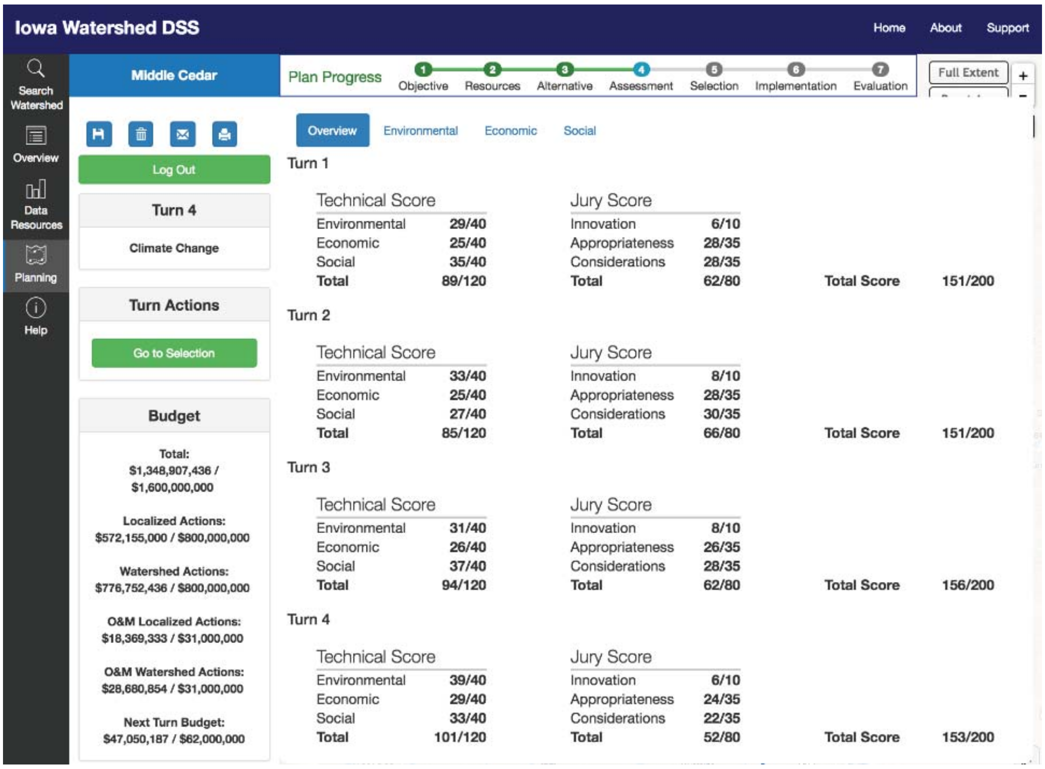

Fig. 4. The score of a team participating to the tournament

Scoring. The scoring of each team's watershed management strategy was based on several different factors. The scoring of the economic, social, and environmental outcomes associated with a team's selected adaptation options were scored using the library of simulations embedded in the IoWaDSS database, with each category accounting for 20% of a team's total score. The IoWaDSS interfaces that automate the score-keeping and budget tracking during the tournament is illustrated in Figure 4.

III. CYBERINFRASTRUCTURE COMPONENTS

The IoWaDSS platform was developed using Single-Page Application (SPA). The platform was built with open source technologies that make the system light-weight, low-cost, and flexible [15]. Conceptually, IoWaDSS is a domain specific web-based Problem Solving Environment - PSE [16]. The PSE structure entails four modules: (1) the watershed characterization (offering a digital representation of the existing data about the watershed), (2) the watershed planning (new data and information created with multi-domain modeling), (3) the competitive gaming environment (enabling game-like competitions), and (4) the plan evaluation (entailing a metric for evaluation of the proposed alternatives and scoring of the competitors). Figure 5 illustrates the PSE modules and associated components.

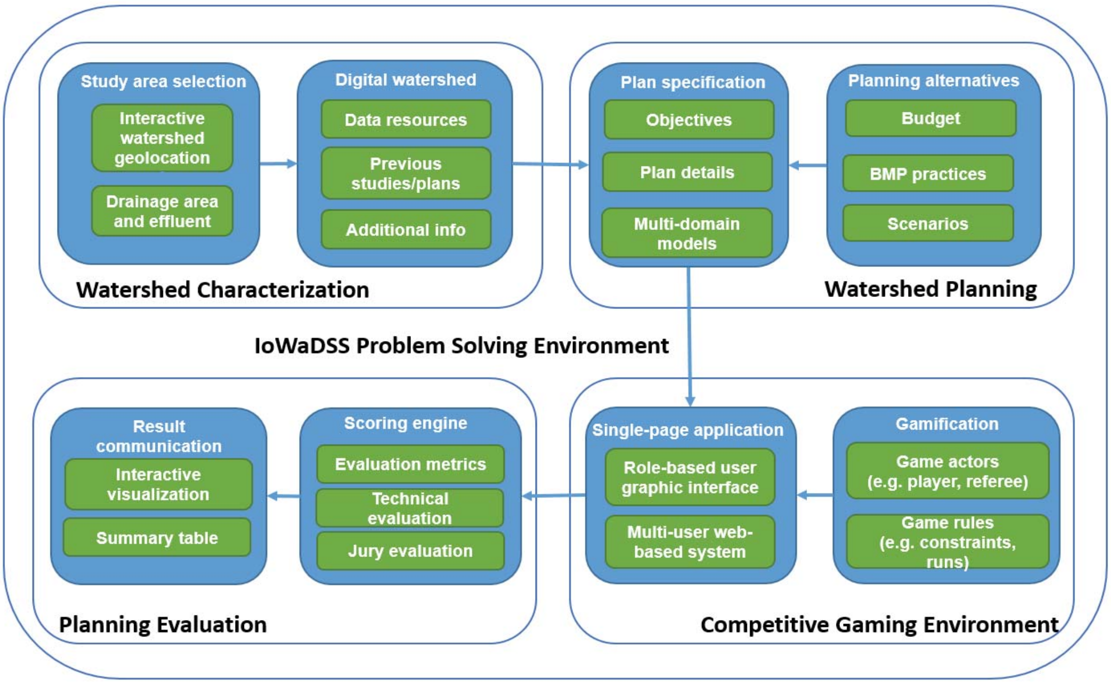

Fig. 5. Problem Solving Environment structure for the IoWaDSS prototype

Following the modern web-application templates, the IoWaDSS, adopts a three-tier architecture that includes the following components: (1) presentation, (2) logic, and (3) data. To ensure the platform reliability, flexibility, extendibility, modularity, and maintainability, industrial design patterns and architecture patterns (e.g. MVC and MVVM) are applied in the system development. Figure 6 illustrates the overall architecture, along with the web, informatics, and GIS technologies that are associated with each tier.

The presentation tier is primarily rendered at the front-end in user's web or mobile browser. It contains platform elements that a user can see and interact with. This tier provides users with Graphic User Interfaces (GUI), a map engine, and visualization tools to facilitate map operations, information retrieval, workflow control, watershed planning, and communication. The presentation tier in IoWaDSS entails four components: (1) the map engine, (2) the GUI, (3) logic management, and (4) the visualization tools. The map engine is the means to visualize geo-spatial information, such as basemaps, river networks, watershed boundaries, locations of BMPs, and modeling results (e.g. soil maps, inundation maps). For IoWaDSS, the presentation tier is developed with Leaflet JavaScript (JS) library and its extensions. The GUI provides a media for users to navigate through the platform, to manage and control tools, and to retrieve information. The GUI is developed using JQuery and Bootstrap JS library, which guarantees both the user interactivity and compatibility for multi-screen sizes.

The logic management component contains a front-end Model–view–controller (MVC), that improves fluid web page design and two-way data-binding. The main reason to have a logic management component is that our platform contains SPA, which make the front-end very heavy. The front-end

MVC, a JavaScript library itself, helps structure and optimize the front-end developments with practical industrial conventions, which increases the maintainability and extendibility at the front-end. Visualization tools are primarily responsible for visual communication and representations (e.g. plots, chart). They are developed with D3.js and HighChart libraries, both of which are data-driven and user-responsive. The entire presentation tier is developed using common front-end technologies (e.g. JavaScript, HTML, and CSS). To perform multiple system operations (e.g. updating data & information, displaying spatial features on a map, user log-in, saving user-defined watershed plans), the presentation tier sends Asynchronous JavaScript and XML (AJAX) requests to exchange information with the server-side applications in the form of JSON, XML, and images.

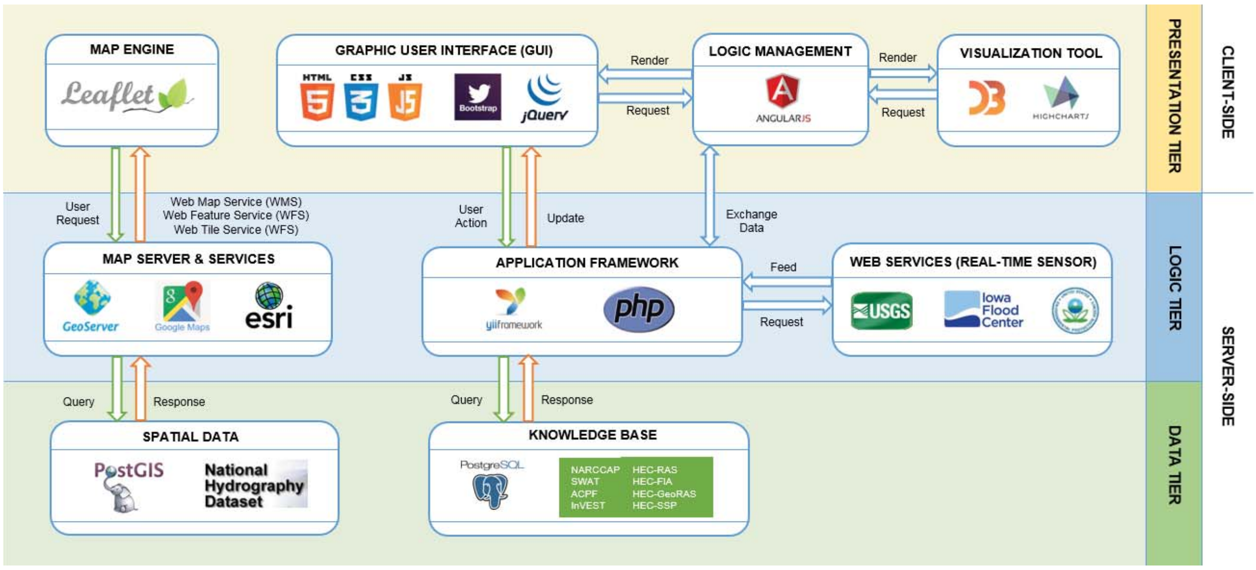

Fig. 6. Overall architecture

Unlike the presentation tier, the logic tier and data tier are deployed on the server-side (i.e., "back-end" of the platform). The logic tier is responsible for organizing the data, assembling the services based on relationship between the user scenarios and the models, and for providing the necessary information requested by the presentation tier. The logic tier consists of three sub-components: (1) the map server and map services, (2) the application framework, and (3) the web services for real-time sensors. The map server and web services prepare and manage spatial information, as well as handle request from the presentation tier for the map visualization. The IoWaDSS uses GeoServer, an open-source map server application, to host spatial information that is stored locally on the server (e.g. river, watershed boundaries). The GeoServer complies with a number of open standards, such as Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS), which improve the interoperability of spatial data effectively. Third-party map services from Google and ESRI are also used to increase the diversity of the basemaps (e.g. satellite imagery, topo-maps, and NHD basemap) within the platform. The application framework components manage the overall back-end logic (e.g. scientific models, PSE design, and data integration) and user-scenarios (e.g. multi-user web-based system).

Many of the platform's tool and applications (e.g. watershed search engine) are hosted in the application module. This module hosts and is responsible for managing the local web services. The system design adopts a Service Oriented Architecture (SOA) to bring multiple web services in one place. There are two types of web services in the IoWaDSS: (1) local web services (that are developed within the application framework on the local server), and (2) external web services (that are hosted on third party servers). External web services in IoWaDSS are mainly third-party data providers (e.g. USGS, EPA). The web services are important components for the presentation tier as they facilitate the communication between the presentation and the logic tier. The backbone of the application framework module is Yii (a PHP framework that also follows the MVC pattern).

The data tier is located at the bottom of the architecture. This tier consists of databases and datasets. The spatial data are stored in the PostGreSQL database with its PostGIS library, which adds support for the use and management of spatial objects. The knowledge base is the customized database that stores results of simulations with the 8 multi-domain models and their relationship as entities.

IV. Conclusions

The serious gaming environment described in this paper represents a realistic problem solving environment that include users-defined problems, strategies selection, visualization and analysis of modeling results, and problem solving tasks orderly executed through player interaction. By using a game-like environment, the traditional watershed planning is converted into a competitive game that promotes social learning through teams playing out potential adaptation strategies to reduce flood risk while addressing water quality issues. Gaming environments create shared knowledge spaces where interactive and iterative actions can be tested or 'played out' by participants. The co-production of the decision making with the involvement of management agencies and local stakeholders presented in this paper has potential to improve the quality and efficiency of the decision-making process. By transferring the roles in the actual decisions, this approach increases considerably the viability of the plan implementation as the local stakeholders are co-owners of the plan.

The IoWaDSS user-friendly interfaces allowed the teams to consider holistic and systematic approaches to deal with water-related hazards by enabling players to share their knowledge and the local perspectives on the issues in a manner that they have not experienced before. According to a post-tournament survey, 71% of the participants were favorable to the idea of using the tournament results to inform future decisions. For this purpose, participants have been given permanent access to the decision support tool (http://iowawatersheds.org/dss/tournament) so they can go back and examine each team's choices, plans and outcomes to continue informing decisions going forward.

The IoWaDSS used for delivery of the MHT serious-gaming prototype presented in this paper is one of the possible paths to engage the community in the planning process by reducing the complexity of the technical aspects and providing a problem-solving environment that is understandable and adapted to the technical skills of the local watershed stakeholders. A user-friendly and interactive prototype of IoWaDSS was developed by seamlessly integrating open-source Web GIS tools, multi-domain models, real-time sensor network, and other open-source components and libraries. Compared to other generic watershed decision systems, the IoWaDSS has implemented unique computational concepts: an integrated and modular framework and game-based concepts in collaborative watershed planning.

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References

[1] Nisbet, M.C. and Markowitz, E. (2015). Public engagement research and major approaches, Commissioned Annotated Bibliography in Support of the Leadership Institute American Association for the Advancement of Science, Washington, D.C.

[2] Evers, M., Jonoski, A., Maksimovic, C., Lange, L. Rodriguez, S.O., Taklesadik, A., Cortes Arveal, J. Almoradie, A., Simoes, N.E. Wang, L. and Makropoulos, C. (2012). Collaborative modelling for active involvement of stakeholders in urban flood risk management, Natural Hazards and Earth System Sciences, 12, 2821-2842.

[3] Voinov, A., Kolagani, N., McCall, M.K., Glynn, P.D., Kragt, M.E., Ostermann, F.O., Pierce, S.A. and Ramu, P. (2016). Modelling with stakeholders – Next generation, Environmental Modelling & Software, 77, 196-220

[4] Di Baldassarre, G., Brandimarte, L. and Beven, K. (2016). "The seventh facet of uncertainty: wrong assumptions, unknowns and surprises in the dynamics of human-water systems," Hydrological Sciences Journal, 61(9), 1748-1758, DOI:10.1080/02626667.2015.1091460

[5] Pretty, J. (2003). Social capital and the collective management of resources, Science, 3002, pp. 1912-1914.

[6] Giupponi C., Mysiak J., Depietri Y. and Tamaro M. (2011). Decision Support Systems for water resources management: current state and guidelines for tool development, In: Vanrolleghem P.A. (Ed.), Decision Support for Water Framework Directive Implementation. IWA Publishing: London (UK), pp. 107-202.

[7] Muste, M. (2014) Information-centric systems for underpinning sustainable watershed resource management, Chapter 13 in "Comprehensive Water Quality and Purification," Ahuja S. (Ed), vol 4, Elsevier, 270-298.

[8] Maidment, D. (2005) Editor. "Hydrologic Information System Status Report," CUAHSI Report, Version 1, University of Texas, Austin, TX

[9] Tarboton, D. G. (2014). *HydroShare: Advancing Collaboration through Hydrologic Data and Model Sharing*. NCSA Colloquium and CyberGIS Distinguished Speaker Series. University of Illinois, Urbana Champaign. http://events.ncsa.illinois.edu/vts/video/NCSA/Colloquia/tarboton.mp4

[10] Famiglietti, J., L.Murdoch, V.Lakshmi, and R. Hooper (2008), Community modeling in hydrologic science, Eos Trans.AGU,89(32), 292.

[11] Iowa Flood Information System: iowafloodcenter.org/ifis/en

[12] California Data Exchange center: http://cdec.water.ca.gov.

[13] Muste, M., Smith, J., Demir, I., Carson, A. (2017). "Serious Gaming for Community Engagement in Multi-Hazard Mitigation" Hydrolink, International Association of Hydro-Environment Engineering and Research, Madrid (IAHR), Spain

[14] Xu, H., Hameed, H., Demir, I., Muste, M. (2016). Visualization Platform for Collaborative Modelling, 2016 AWRA Summer Specialty Conference - GIS and Water Resources IX, American Water Resources Association, July 11-13, 2016, Sacramento, CA.

[15] Xu, H., Hameed, H., Windsor, M., Muste, M., Demir, I., Smith, J., Hunemuller, T., Stevenson, M. B. (2017). Decision-support System for Underpinning Collaborative Planning for Multi-hazard Mitigation," Proceeding 37th IAHR World Congress, August 13-18, 2017; Kuala Lumpur, Malaysia.

[16] Rice, R.J. and Boisvert, F.R. (1996). Environments, from scientific software libraries to problem-solving. IEEE Computational Science & Engineering, 44-53.