Water Resources Center Annual Technical Report FY 2005

Introduction

The Rhode Island Water Resources Center is continuing to enhance its operations. On September 9, 2005, the Rhode Island Water Resources Center hosted a meeting of the five New England Water Resources Center directors at the University of Rhode Island Bay Campus. At this meeting we discussed areas of cooperation to enhance funding opportunities by focusing on regional issues. This meeting was followed up by a meeting which was hosted by NEIWPCC, of the WRC Directors on Monday, January 9, 2006 in Lowell, MA. Representatives of NEIWPCC were briefed on the mission of the Water Resouce Centers in New England and are beginning the process of exploring joint funding opportunities.

The RI WRC has published two newsletters which have been added to the website as well as being distributed to state and federal representatives. In FY 06/07 projects have been funded which include a research project at Roger Williams University, which represents the first time that a proposal was submitted and funded from an institute other that the University of Rhode Island. The other project of note is an outreach to host a summer science/engineering camp for High School students. This project will also include the first ever state-wide water resources conference.

Research Program

The Rhode Island Water Resources Center supported one research project; MTBE Drinking Water Contamination in Pascoag, RI: A Tracer Test for Investigating the Fate and Transport of Contaminants in a Fractured Rock Aquifer. The MTBE contamination problem in Pascoag, which contaminated the only public drinking water well for Pascoag, is one of the largest in the country and probably the largest in New England. The RI-DEM has allowed researchers from URI to investigate the MTBE bedrock contamination and suggest remediation alternatives. The data generated during the proposed tracer test will permit the calculation of travel times and other hydrologic parameters that are needed to better prodict the fate of MTBE and other petroleum hydrocarbons present within the Pascoag fractured rock aquifer. This contamination site will become a one-of-a-kind field laboratory for hands-on teaching. By having students work next to environmental professionals and regulators, the best possible outcome will be achieved: students can apply their scientific knowledge and skills by becomming directly involved in solving a pressing, real-world environmental problem.

MTBE Drinking Water Contamination in Pascoag, RI: A Tracer Test for Investigating the Fate and Transport of Contaminants in a Fractured Rock Aquifer

Basic Information

Title:	MTBE Drinking Water Contamination in Pascoag, RI: A Tracer Test for Investigating the Fate and Transport of Contaminants in a Fractured Rock Aquifer
Project Number:	2005RI27B
Start Date:	3/3/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2
Research Category:	Ground-water Flow and Transport
Focus Category:	Solute Transport, Water Supply, Toxic Substances
Descriptors:	
Principal Investigators:	Thomas Boving

Publication

1. Allen, James L., 2006, Assessing the Effect of Fluctuating River Stage on a Discharging MTBE Ground-Water Plume, Pascoag, RI, "MS Dissertation," Geosciences, College of the Environment and Life Sciences, University of Rhode Island, Kingston, RI.
2. Allen, L.J. and Boving, T.B., 2006, Summary of an Aquifer Test with new Conclusions on Groundwater Flow Dynamics, Pascoag, RI, A Report to be submitted to the Rhode Island Department of Environmental Management.
3. Allen, J.L. and Boving, T.B., 2006, Assissing the Effect of Fluctuating River Stage on a Discharging MTBE Ground-Water Plume, Pascoag, RI, Rhode Island Water Resources Center, University of Rhode Island, Kingston, RI.

Summary

Ever since 2001, when Pascoag's only public drinking water well was shut down because of MTBE contamination, the people of Pascoag are without a drinking water source of their own. The MTBE problem at Pascoag is one of the largest in the country and probably the largest in New England. While Pascoag is large, it has almost all common MTBE problems in the New England region: drinking water, bedrock, and river contamination. The Rhode Island Department of Environmental Management, RI-DEM, has agreed opening the Pascoag site to scientists and students from the University of Rhode Island. The overarching objective was to work towards a systematic investigation of MTBE bedrock contamination and a prognosis for remediation alternatives. In this report we describe the results of a pump test that was designed to investigate the fate and transport of MTBE. A conservative tracer test was also carried out, but it had to be terminated before tracer breakthrough at the pumping well occurred. The data generated during this pump test was amended with data from groundwater monitoring wells up-gradient from the production well and a statistical evaluation of fracture analysis data. The principal finding was that the MTBE concentration in the production well can be controlled by the pump rate. That is, the MTBE concentration increases beyond the limit (40 μg/L) set by the RI Department of Health when pumping the production well at 240 gpm, but remains below that limit when pumping at a lower rate (150 gpm). It may therefore be possible by carefully adjusting the pumping regime and continuously monitoring the hydraulic and chemical conditions at the site to produce at least some amount of water from the aquifer. Because the pump test was comparably short (approximately 6 weeks), it is recommended to follow up with a step-up pumping rate test and, more importantly, longer (e.g., 6 months) pump test to ensure that the MTBE concentration remain at low levels over extended periods of time.

Introduction

The Pascoag Water District serves about 5,000 people in the Town of Pascoag, RI. Their drinking water was pumped from *one* 16" well, drawing 350 GPM from both the bedrock and overburden aquifers. On August 30, 2001, a resident of Pascoag noticed an odor in his water. A chemical analysis confirmed that the drinking water was contaminated with MTBE.

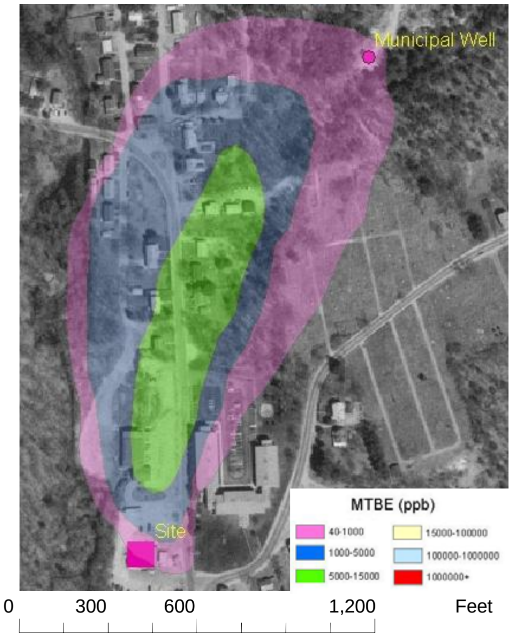


Figure 1: Currently known extend of the Pascoag MTBE plume in the bedrock aquifer.

The acronym MTBE is short for a synthetic organic compound chemically known as methyl tertiary-butyl ether. MTBE is a volatile, flammable, colorless liquid at room temperature and has a terpentine-like odor. MTBE is informally known as a fuel oxygenate because it provides extra oxygen for the internal combustion process ("anti-knocking agent"). MTBE has been used in U.S. gasoline at low levels since 1979, replacing lead-organic compounds as octane enhancer. Since 1992, MTBE has been used at higher concentrations (approx. 10%) in some gasoline to fulfill the oxygenate requirements set by Congress in the 1990 Clean Air Act Amendments. MTBE is now recognized as a very serious threat to groundwater. MTBE contamination is very difficult and expensive to cleanup and is becoming the most common drinking water problem faced by state agencies today.

Following the detection of MTBE in the drinking water, Pascoag residents were immediately notified that they should not drink the town water and minimize skin contact. Nonetheless, residents complained about massive headaches, vomiting, wheezing, and blisters on their lips. Ever since 2001, when the drinking water well was shut down, the people of Pascoag have been without a drinking water source of their own.

Responding to Pascoag's drinking water emergency, the Burrillville School District opened up the hockey rink for residents to take showers and fill water jugs. In the following months, the RI Department of Environmental Management (RI-DEM) supplied the Pascoag residents with about a quarter million dollars worth of bottled water. Currently, Pascoag is receiving water from village/district of Harrisville (both within the Town of Burrillville) at a cost of more than $1,000,000/year. Pascoag cannot sustain this financial burden and may soon become insolvent. Because no other drinking water resources are available, there is strong political pressure building to reactivate the Pascoag well.

RI-DEM identified a nearby gas station as the source of the MTBE. After the owner of the gas station declared bankruptcy, RI-DEM took over all assessment and remediation activities (Project Manager Mike Cote (401) 222-2797, ext. 7118). During the emergency site investigation over 6" of free gasoline was found in some wells. Intrusion of toxic vapors demanded the temporary evacuation of 200 senior citizens from a nearby home for the elderly. By now the MTBE contamination plume is approximately 20 acres in size and up to 100 feet deep. This makes the MTBE problem at Pascoag one of the largest in the country and probably the largest in New England.

The contamination resides in both the overburden and fractured bedrock aquifers and has been consistently detected in a nearby river, too. Bedrock contamination is very complex and expensive to cleanup. It is a common problem in New England as its bedrock aquifers are susceptible to this contamination, due to their being relatively shallow. Currently MTBE in the bedrock aquifer reaches to a maximum of 15,000 μg/L. For comparison, the RI drinking water limit for MTBE is 40 μg/L.

To date, over 50 shallow and deep overburden wells and 16 bedrock wells were installed by RI-DEM. Over 3 million gallons of contaminated water and over 3,000 gallons of gasoline were pumped so far. Funding for the site investigation and water treatment has been provided by the U.S. EPA. EPA's assistance prevented the Rhode Island Leaking Underground Storage Tank (LUST) program from immediate collapse. RI-DEM has now reached a critical decision point – either focusing the remaining funds on constructing a water treatment plant and reactivation of the public well to allow some degree of normalcy to return to the area. Or, concentrate on remediation of the bedrock contamination problem, which – if remained untreated – may again jeopardize the water quality in the future - even after a treatment system has been installed.

The main objective of this pilot-scale field project was to development a conceptual model of MTBE fate and transport within the drinking water aquifer at the Pascoag site. The principle means of generating these data were a tracer test and water quality analysis. Also, the study of this MTBE site served students as an experiential learning opportunity as they were working next to environmental professionals and regulators. Ultimately, the results of this study are expected to produce hydraulic and chemical data in support of RI-DEM and the Town of Pascoag in attempt to reopen the well field.

Methods, Procedures, and Facilities

In cooperation with RI-DEM, more than 60 wells were installed at the site, including many nested wells (i.e. closely spaced wells penetrating different depths of the aquifer). The depth of the wells ranges from 10 ft (overburden) to over one hundred feet into the fractured bedrock. The actual production well (PW3A) is 64 ft deep and penetrates the fractured bedrock aquifer approximately 10 ft.

Starting March 14, 2005, a pump test was conducted at PW3A. The flow rate was recorded at the well head and water level elevations were measured using a vented InSitu data logger. Additional wells were monitored manually and by loggers installed in wells MW18D, MW20S, MW20D, MW28BR, where S and D stand for shallow and deep overburden wells, respectively, while BR is a bedrock well. Precipitation data was recorded at a NOAA weather station located 13 miles south in South Foster, Rhode Island.. Bedrock well LE2 and overburden well MW14D were used as tracer injection wells.

From March 14 through April 19, 2005, the pump rate was 240 gpm. For the last day of the test, April 20, 2005, the pump rate was decreased to 150 gpm. Water samples for MTBE and tertiary amyl methyl ether (TAME), another gasoline oxygenate, were collected on a daily basis starting the day before the beginning of the pump test. All samples were collected in 40 mL VOA vials and preserved with 6N hydrochloric acid with zero headspace. All these samples were analyzed by EPA method 8260B (Low QL) for volatile organic compounds (VOC) and oxygenates by Premier Laboratory (Dayville CT). Samples collected between 04/03/05 and 04/08/05 were collected but not analyzed.

A conservative tracer (fluorescein) was released in well LE2 A total of 50 g fluorescein was pre-dissolved in 1000 ml of deionized (DI)and injected into LE2 at once. The tracer was released one day after the pumping rate was decreased from 240 to 150 gpm. About 100 ml tracer samples were collected on hourly basis. Fluorescein was analyzed by UV-Vis spectrometry (Shimadzu) at a wavelength of 491 nm.

A fracture analysis at bedrock outcrops on and near the site was carried out and statistically evaluated for dominant fracture orientation. Measurements of lineation, foliation, and fracture orientations were collected using a *Silva Compass*. Fracture strikes were plotted on rose diagrams using the *Rockworks* software for plotting individual locations and groups of measurements.

Results

The locations of those wells utilized in this study are shown in Figure 2. Figure 3 shows the water table elevation under non-pumping conditions, while Figure 4 shows the water table under pumping conditions (240 gpm).

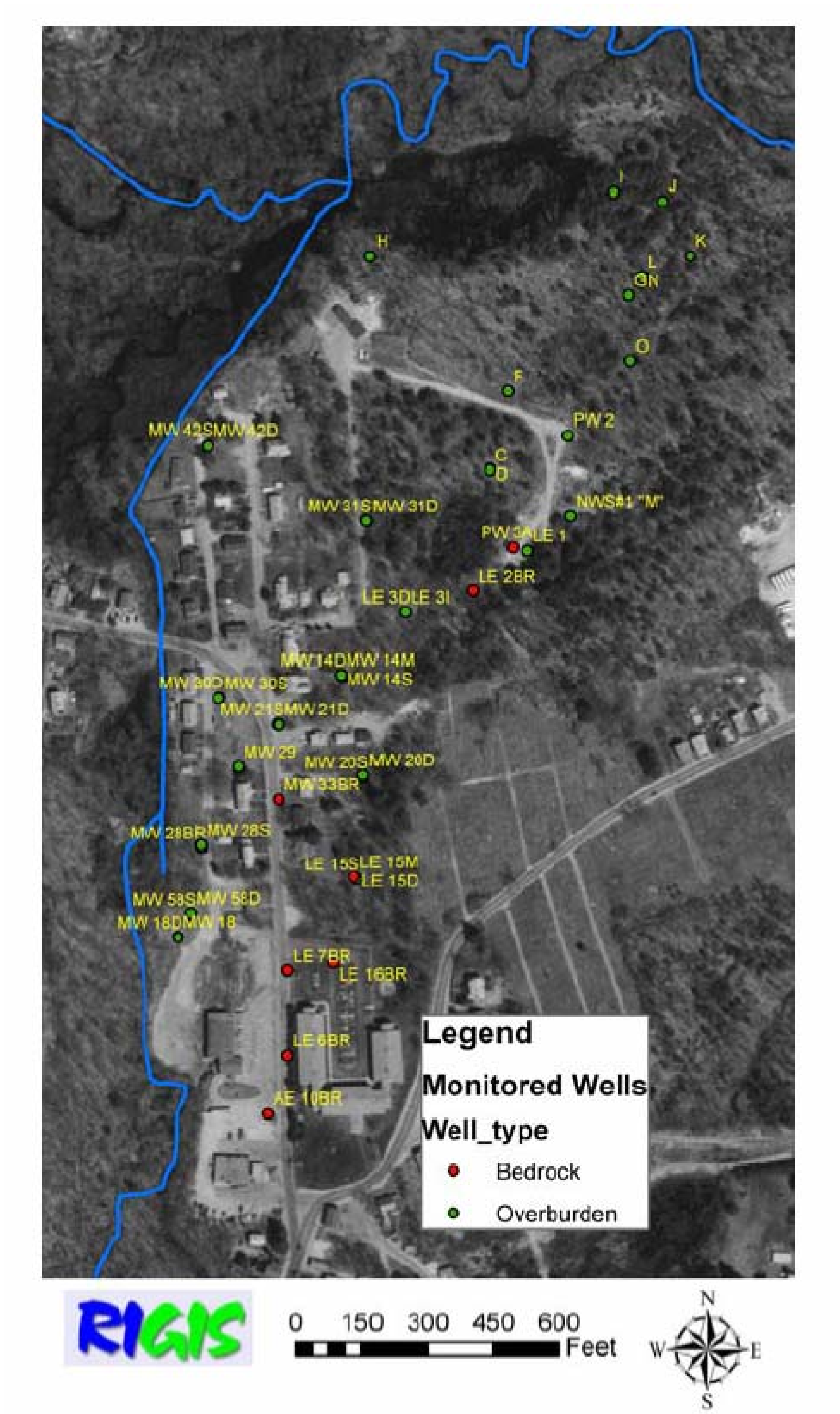


Figure 2: Location of monitoring well utilized in this study.

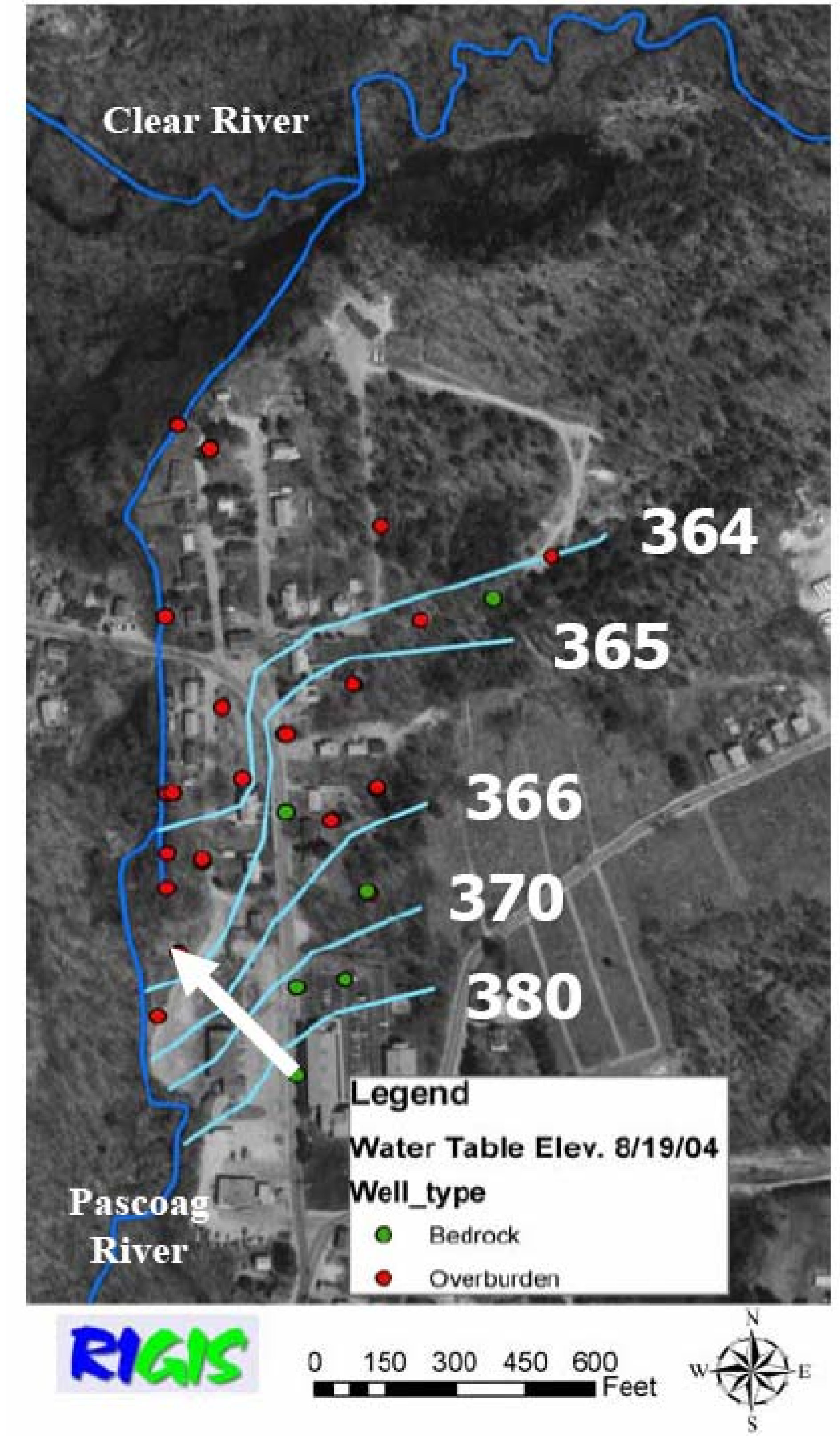


Figure 3. Water table of site under non-pumping conditions. Table drawn using combined bedrock and overburden wells. Uneven contour interval

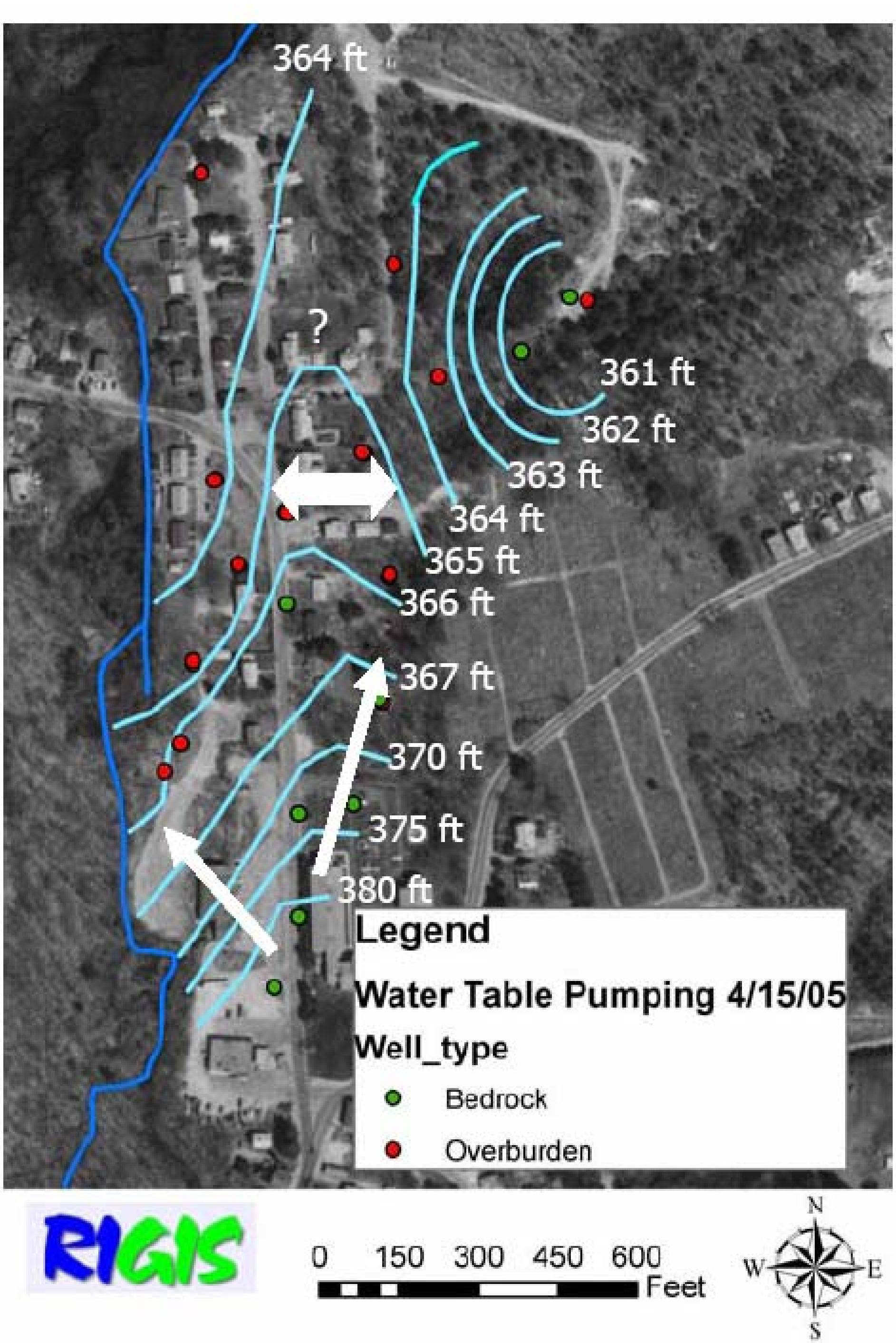


Figure 4. Water table gradient under pumping conditions of 240 GPM. Notice plume separation and the flow divide in middle of the site. Uneven contours

The water table elevations in the pumping and observation wells are summarized in Figure 5. Also shown are the precipitation measurements. There were two significant precipitation events during the aquifer test. These events occurred on March 28 and April 2, with amounts of 2.8 and 2.5 inches respectively.

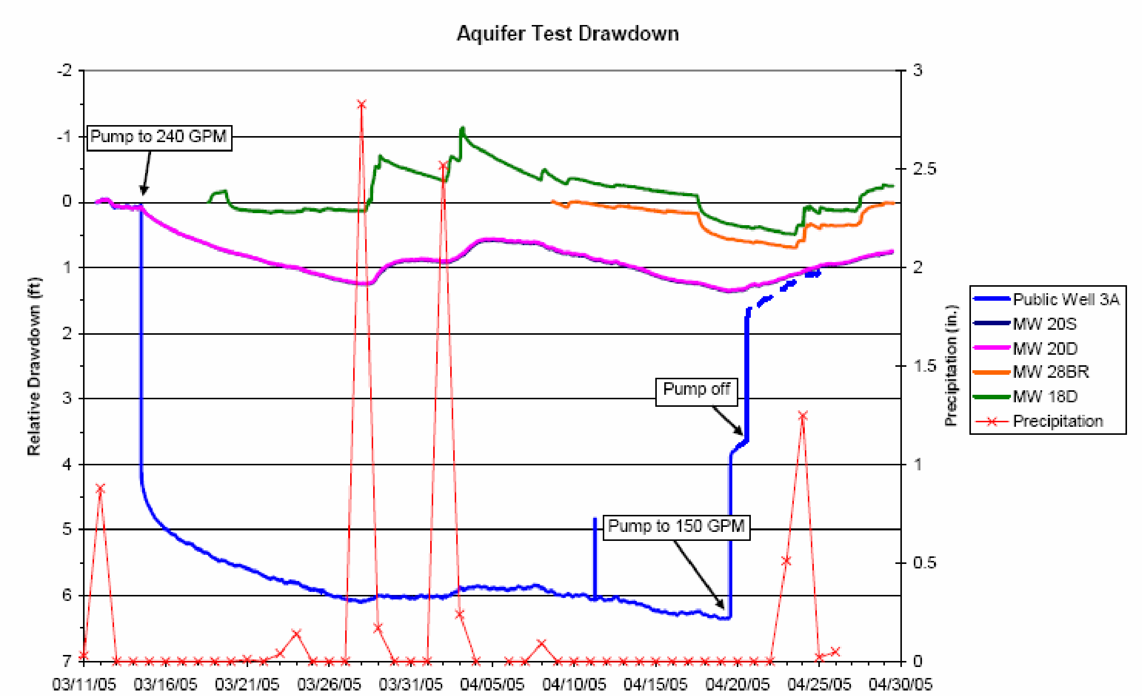


Figure 5: Drawdown curves obtained from pressure transducers. Precipitation is also plotted. The origin of the anomalous point in Public Well #3A on 4/10/05 is unknown. It may have been related to a very short pump disruption.

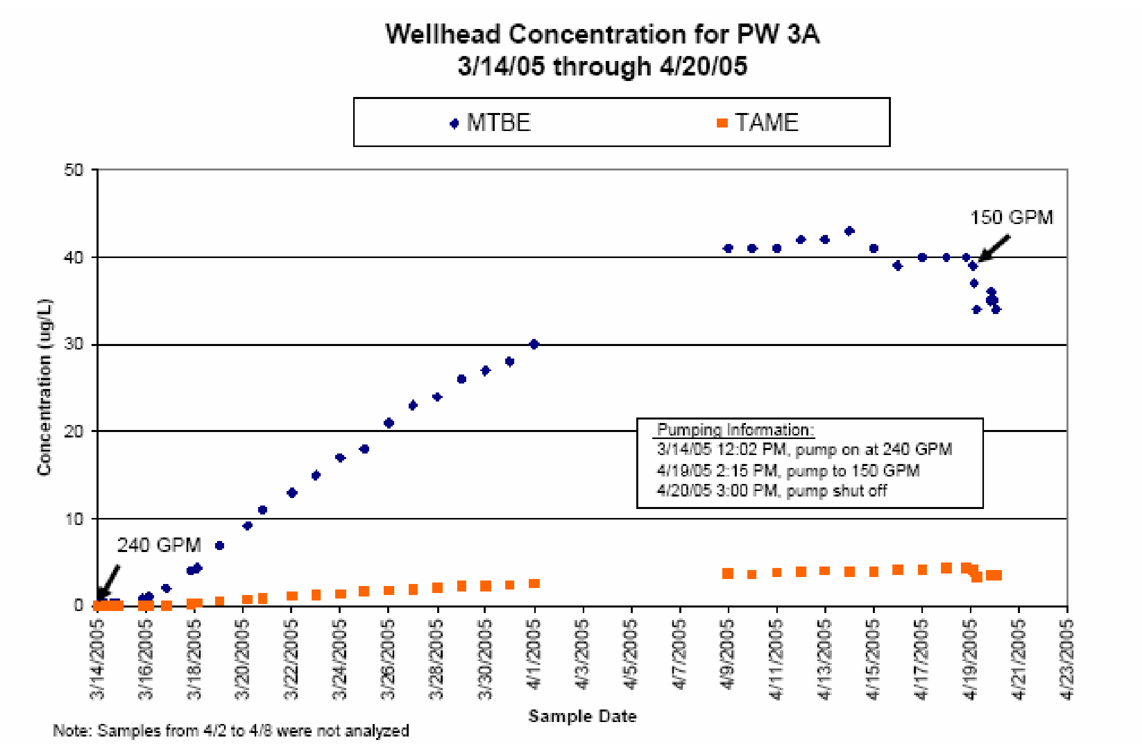


Figure 6: Concentrations of MTBE and TAME at the wellhead from the start of the aquifer test through the end. Notice the apparent steady state at 43 µg/L for MTBE and the drop when pump rate changed.

Water Quality Data
The results of the water analysis at the production well head are summarized in Figure 6. MTBE and TAME were detected in every sample after the first few days. MTBE levels increased asymptotically and peaked at 44 μg/L on 04/14/2005. TAME levels never exceeded 5 μg/L.

After injection of the fluorescein tracers (04/20/2005), samples were collected for only 4 hours. The reason for this short sampling period was that the pump test was shut down on 04/20/2005 by the Pascoag Utility District because MTBE levels had exceeded the 40 μg/L limit. This was unfortunate because at the time of the shut-down, MTBE levels had dropped to less than 40 μg/L , presumably in response to lowering the pump rate to 150 gpm. Because there was a 14-day lag time between sampling and availability of laboratory results, the shut down was ordered without knowing that a drop in MTBE concentration had occurred. Once the pump test was shut down, it was not possible to restart the pump test again.

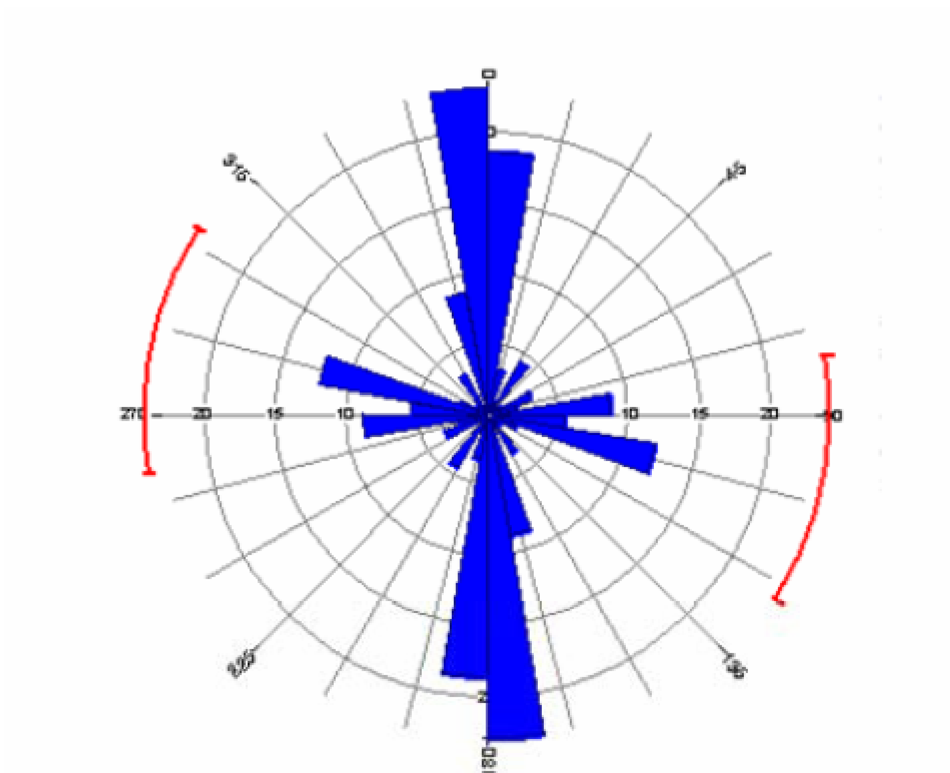


Figure 7: Average fracture strike for all field measurements

Fracture Analysis
The results of the fracture study (91 total observations) indicate that there are two dominant fracture orientations in this area. The trend of mineral lineation is approximately N2E and plunges at 10° to the north. The dominant fracture orientation is nearly parallel to the mineral lineation and has an average dip of 65E. The other less dominant fracture orientation is N75W and dips 75S. Figure 7 shows the average strike of all fractures measured. Slight variation and other orientations do occur, however the frequency and transmissivity of these fractures is less significant. Orthogonal fractures that trend along the same dominant strike but dip much more shallowly also occur. The frequency of the N75W trending fractures appear to be concentrated in localized fracture zones. Between these zones the rock units are massive. The N2E fractures are more regular and their frequency is more consistent.

Discussion

The results of the water table elevation measurements before and during the pump test clearly indicate that the production well – even when pumped at a lower rate than during pre-contamination production (300 gpm) – strongly influences the groundwater gradient and pulls MTBE from the source zone towards the well head. Under no-pumping conditions the MTBE appears to migrate away from the well field and towards the river in an approximately north-north-easterly direction. The natural direction of the groundwater movement seems to be controlled by fractures running in approximately south-to-north direction and by the presence of the river. Also, the response of the water table elevation to precipitation is almost instantaneous suggesting that there is a good hydraulic connection between the surface and the aquifer.

The shape of the MTBE concentrations graph indicates that a quasi-equilibrium concentration level between 40 and 50 μg/L MTBE is being approached when the pumping rate is at 240 gpm for about 4 weeks. Once the pumping rate was lowered to 150 gpm, MTBE concentrations dropped below the regulatory threshold limit of 40 μg/L. This suggests that by carefully controlling the pumping rate, water of drinking water quality can be pumped from the aquifer. Because the aquifer test ended prematurely, the injected conservative tracers had not arrived at the pumping well.

The analysis of the test data has led to a better understanding of the ground water flow, contaminant transport, and ground water/surface water interactions. The goal was to determine how and where contaminants are moving and if it is possible to eventually reactivate the well. Major new advancements regarding water table gradients, plume stabilities, contaminant transport pathways, and the aquifer/surface water interactions have now been made. Based on these findings it is suggested to design a stepped pumping test and monitor the water quality in the production well as well as in up-gradient wells for at least 6 months duration. Ideally, this stepped pumping test should give evidence for, potentially, a threshold pumping rate at which the MTBE concentrations will remain below the drinking water limit.

Acknowledgements

This study was made possible by a grant from the RI Water Resources Center and support by RI Department of Environmental Management and the Town of Pascoag.

Information Transfer Program

The RI Water Resources Center supported two Information Transfer Projects; Development of a Statewide Public Water-Supply GIS Coverage for Rhode Island and Risk Assessment Methods for Water Infrastructure Systems.

The project entitled, "Development of a Statewide Public Water-Supply GIS Coverage for Rhode Island," addressed the need for a unified statewide spatial inventory of public water-supply line and service areas in Rhode Island by assembling the existing supplier-specific water line and service area spatial datasets into a unified statewide geographic information system coverage. Although spatial data existed for the 32 individual water-supplier service areas, there was no current unified statewide spatial inventory of these service areas and the existing attribute tables varied between the different datasets. This project, more specifically, cataloged the existing spatial data sets for supplier-specific water lines service areas and completed the steps needed to assemble the spatial data into a unified and internally consistent spatial database of public supply service areas in Rhode Island. This unified spatial dataset with the accompanying maps and fact sheets will provide the water-supply infrastructure data needed for effective development of State Guide Plan elements and planning associated with development of state and local land-use plans, emergency drought response and interconnections and supplemental water investigations.

The project entitled, "Risk Assessment Methods for Water Infrastructure Systems," involved the development and adoption of a comprehensive and systematic approach to securing homeland water infrastructures. An infrastructures security permeates all aspects of its planning, design, construction, operation and maintenance. Major infrastructure security themes address the following: 1) the identification of critical assets (system analysis), 2) the assessment of risk (systematic evaluation of critical assets in terms of their susceptibility and the assessment of consequences through scenario enactment) and 3) the derivation of responses (mitigation actions that restore the system to partial or full operation). The proposed study reviewed the worldwide state-of-practice in assessing risk at water infrastructures in the aim to adopt a standard methodology for Rhode Island facilities. Standard selection was based on the breath of coverage of the relevant security themes and on method effectiveness and efficiency.

Development of a Statewide Public Water-Supply GIS Coverage for Rhode Island

Basic Information

Title:	Development of a Statewide Public Water-Supply GIS Coverage for Rhode Island
Project Number:	2005RI32B
Start Date:	3/6/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	RI District No. 2
Research Category:	Engineering
Focus Category:	Management and Planning, Water Supply, None
Descriptors:	
Principal Investigators:	Anne Veeger, Nasir Hamidzada

Publication

1. Veeger, A., 2006, Development of a Statewide Public Water-Supply GIS Coverage for Rhode Island, Rhode Island Water Resources Center, University of Rhode Island, Kingston, RI.

Introduction

The State of Rhode Island requires accurate water-supply infrastructure data for effective development of State Guide Plan elements and planning associated with development of state and local land-use plans, emergency drought response, emergency interconnections and supplemental water investigations. A key element of the water supply infrastructure is the spatial distribution of public water-supply lines and service areas. Although spatial data exist for the 32 individual water-supplier service areas, there is no current unified statewide spatial inventory of these service areas and the existing attribute tables vary between the different datasets. The absence of a unified spatial dataset limits the ability of State agencies (i.e. Rhode Island Water Resources Board RIWRB, Department of Health) to accurately catalog the water-supply infrastructure and develop/address planning elements related to public water supply.

Nature, scope, and objectives of the project including a timeline of activities.

This project addresses this need by assembling the existing supplier-specific water line and service area spatial datasets into a unified statewide geographic information system (GIS) coverage. Establishing this unified GIS provides the State with a tool it needs to analyze and plan at a variety of scales such as individual water supplier, town, watershed, county or statewide. In particular, the updated coverages and maps proposed in this project will assist the Rhode Island Water Resources Board's (RIWRB) Water Allocation program and local technical assistance to water suppliers, planners and municipal officials relating water supply information to watershed capacity.

The objectives of the project are:

- Compilation of the existing water-supply service area spatial coverages.
- Unification of individual coverages into an internally consistent state-wide spatial dataset.
- Development of maps for technical assistance to state/town officials and for outreach and public education.

This project builds on work previously completed under a Joint Mapping Project between the RIWRB and the RIDOT as well as more detailed work underway on distribution capacities with Maguire Group for a supplemental water supply study. This two-phased study identifies supplemental water supply available for emergencies. As part of the project Maguire will produce new 1:5000 scale water line datasets for each of the 32 public water suppliers in Rhode Island by late January to mid February. The creation of a statewide water line GIS dataset and a statewide water district GIS dataset, are however beyond the scope of that mapping project. The work proposed herein, therefore builds upon and expands the efforts of the previous projects.

Methods

Compilation of existing water-supply service area coverages/shape files and

tabulation of data elements (attributes) present in each coverage - A compilation of the existing public supply spatial data coverages was obtained from Mary Hutchinson (Mapping and Planning Services, Jamestown, RI) a sub-contractor to the RI WRB.

Creation of individual water services areas - A 1000-ft buffer distance, as stipulated by the RIWRB, was generated to reflect approximate water district service areas based on the new 1:5000 scale water line datasets.

Creation and quality control analysis of unified spatial dataset and development of maps – Using the inventory of attributes as a guide, a new attribute table structure was created for the unified dataset. Data from the 32 individual datasets was merged into a unified dataset. The resulting merged product was verified against the original individual datasets to ensure that data integrity was preserved. This unified coverage was used to generate a State-wide map of the public water-supply infrastructure.

Metadata file to document all sources of information used in the unified dataset and create fact sheets – A metadata file consistent with RIGIS standards was prepared.

Results

The results of the project include:

GIS Coverage

A statewide public water-supply spatial dataset formatted for ArcGIS. This spatial data coverage will reside with the RI Water Resources Board and be made available on an as-needed basis to State and local agencies for planning purposes.

The coverage includes the distribution lines and a 1000-ft buffer designating the approximate service area for each of the 32 pubic water suppliers in RI (Table 1).

Table 1. Public water suppliers in Rhode Island.

Block Island Water Works	North Tiverton Fire District
Bristol County Water Authority	Pawtucket Water Supply Board
Cumberland Water Department	Portsmouth Water District
East Providence Public Works	Providence Water Supply Board
East Smithfield Water District	Richmond Water Supply System
Greenville Water District	RI Economic Development Corp.
Harrisville Fire District	Smithfield Water Supply Board
Jamestown Water Division	South Kingstown Water Department
Johnston Water Control Facility	Stone Bridge Fire District
Kent County Water Authority	Tiverton
Kingston Water District	United Water Rhode Island
Lincoln Water Commission	URI Facilities & Operation
Narragansett Water Department	Warwick Water Department
Newport Water Works	Westerly Water Department
North Kingstown Water Department	Woonsocket Public Works
North Smithfield Water Department	Zamborano Memorial Hospital

State Map

A map (also available in PDF format) was also produced to show the distribution network and buffered areas for each public water supplier (Figure 1).

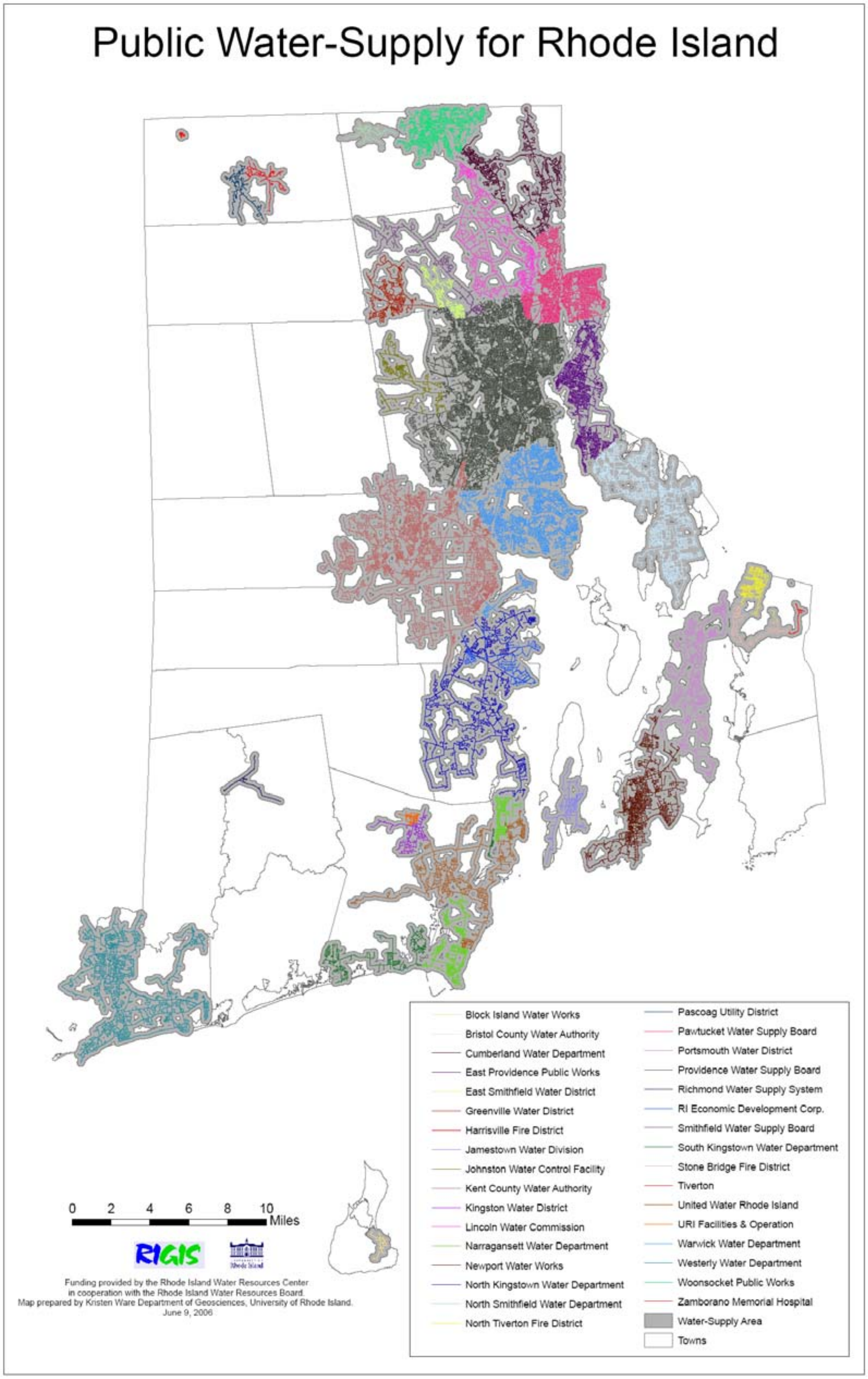


Figure 1. Public water supply areas in Rhode Island.

Risk Assessment Methods for Water Infrastructure Systems

Basic Information

Title:	Risk Assessment Methods for Water Infrastructure Systems
Project Number:	2005RI34B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	02
Research Category:	Not Applicable
Focus Category:	Methods, Treatment, Water Supply
Descriptors:	
Principal Investigators:	Natacha Thomas, Natacha Thomas

Publication

1. Thomas, N., 2006, Risk Assessment Methods for Water Infrastructure Systems, Rhode Island Water Resources Center, University of Rhode Island, Kingston, RI.

Introduction

The latest terrorist acts perpetrated against the nation have sprouted security concerns for its varied infrastructures. Homeland Security Presidential Directive 7 (HSPD-7): Critical Infrastructure Identification, Prioritization, and Protection, released on December 17, 2003, outlined the requirements for protecting the Nation's critical infrastructure including water resource systems. Yet, the common, effective and efficient methods for assessing risk remain obscure to many decision makers. In an attempt to remedy this knowledge void in the state-of-the-practice, this report summarizes the state-of-the-art methods in assessing risk in general and for water resource infrastructures in particular. Excerpts of this report are intended for direct distribution to decision makers in water resource.

According to Jeffrey Danneels, Sandia Laboratories, in testimony to the House on Science Committee, November 14, 2001, approximately 170,000 public water systems provide water to more than 250 million Americans. Public water systems are "water systems that provide drinking water to at least 25 people or 15 service connections for at least 60 days per year." The Environmental Protection Agency (EPA) recognizes two primary types of public water systems: 1) Community Water Systems, which provide drinking water to the same people year-round. Approximately 54,000 community water systems currently serve America's homes. Of these community water systems, about 350 are large enough to serve more than 100,000 customers. 2) Non-Community Water Systems, which serve customers on less than a year round basis. More than 116,000 systems fit this category ***(EPA, 1999)***.

A clean water system has seven main functions in the process flow. Water arrives from a source, having been pumped from a well, river, etc., to a treatment plant. The treatment plant removes impurities from the water which is then channeled to a storage tank. Distribution mains carry the clean water to industry and to service lines towards homes. From industry and homes soiled water enters the sanitary sewer system. Water resource infrastructures represent key nation assets that sustain life, life's quality, economic expansion and prosperity. Thus, they are of great value to the nation's security.

Attacks on water resource infrastructures could disrupt the direct functioning of key business and government activities, facilities, and systems, as well as have cascading effects throughout the Nation's economy and society. Enhanced security features should drive all new designs and retrofits for water utility systems. Risk assessments can help guide and prioritize enhancements.

This report summarizes the varied methods and tools available to the decision maker for assessing risk at water resource facilities. It further presents the advantages and disadvantages of each method and tool. Firstly, it provides working definitions of vulnerability, exposure, risk and quantitative risk assessment. It then reviews and compares conceptual frameworks and classification schemes for risk assessment methods. The exploitation of these frameworks and schemes and of the strength of the reviewed methods leads to guidelines for the selection of risk assessment methods.

Variable Definitions

Scientists in risk assessment, whether from the same or different disciplines, too often speak different languages; permitting different acceptations of the same risk terms

(Gouldby and Samuels, 2005). Numerous definitions exist for the variables of interest in a risk assessment study. These variables include: event or threat, *outcome, scenario,* exposure, vulnerability, consequences, risk. The paragraphs that follow relay in turn the acceptations of these variables utilized herein.

Event/Threat assessment considers the full spectrum of events/threats whether natural, criminal, man-made, accidental or intentional to cause harm for given facilities or locations. The likelihood of each event/threat must be established using available information. This information can be site-specific or general. Site specific data, if available in sufficient quantity and quality, is the most desirable basis for assessing events/threats. For natural events/threats, historical data concerning frequency of occurrence and consequences can be used to determine the credibility of the given event/threat. For criminal events/threats, the crime rate by crime type recorded for similar facilities provides an indication of the same. In addition, the symbolic, strategic, or intrinsic attractiveness, values of the facility as a primary or a secondary target should inform terrorist event/threat assessment.

Exposure

Causative events *and their possible outcomes* do not constitute risk unless there is an exposure to people and the environment. Exposure is mostly defined as the act of subjecting someone or something to an influencing experience. At times, it quantifies the receptors that may be influenced by the event, for example, the number of people and their demographics. Herein we shall adopt the first definition.

In quantitative risk analysis three main aspects/angles of exposure import: its controllability, its pathway and its recipients. The first aspect, controllability of the exposure, ranges from directly and indirectly controllable to the totally uncontrollable by man. Exposure of the environment to the impacts of natural events is generally uncontrollable but its consequences could be minimized by man. The second aspect, the exposure pathway, describes the potential routes to exposure by the influencing experience. It is usually expressed in terms of surface water, groundwater, inhalation or ingestion, etc. For a given outcome to specific recipients, the total magnitude of the probability of its exposure pathways (p_e) must be less than or equal to one. The totality can be less than one because the pathway may diminish the impact of the outcome. For certain exposure the probability is one and for negligible exposure it is near zero. The third consideration, the exposed recipients captures the receptors that may be influenced by the event.

Vulnerability Assessment

The National Water Resource Association (NWRA) (2002) defines a vulnerability assessment as the identification of weaknesses in security, focusing on defined threats that could compromise the ability to provide a service. The definition of vulnerability adopted here is from the National Oceanic and Atmospheric Administration (2002), the susceptibility of resources/assets to negative impacts from threat events. Hence, a vulnerability assessment accounts for the assets that could deter or defray unwanted outcomes from an event and for their susceptibility to failure.

Consequences

When event outcome entails exposure to risk recipients and to the environment, a whole set of possible consequences may occur. Consequences represent the event impacts such as economic, social or environmental damages or improvements and may be expressed quantitatively or descriptively.

Risk Assessment

The department of Homeland Security, 2004, risk assessment is where efforts in asset assessment, threat assessments, vulnerability assessments, incident response, consequence management, and consequence analysis are integrated into a coordinated framework for determining the likelihood and the expected consequences of a suite of events. This integration provides a basis for prioritizing operational and investment decisions. Whereas vulnerability assessments stress the susceptibility to threats, risk assessments stress not only the susceptibility but also the consequences.

LITERATURE REVIEW

Campbell and Stamp, 2004, of Sandia Laboratories, provide a functional classification scheme of risk assessment methods. The intent is to provide meaning by imposing a structure that identifies relationships; thereby enabling informed use of the methods so that a method chosen is optimal for a situation given. The scheme classifies methods based on level of detail, and approach. The below table, Table 1, summarizes the classes derived. Table 2 classifies known risk assessment methods into the derived scheme.

Level		Approach		
		Temporal	**Functional**	**Comparative**
3	Abstract (Expert)	Engagement	Sequence	Principles
2	Mid-Level (Collaborative)	Exercise	Assistant	Best Practice
1	Concrete (Owner)	Compliance Testing	Matrix	Audit

Table 1 Classification Matrix
Source : Campbell and Stamp, 2004

Hence, Campbell and Stamp, 2004, classify the various risk assessment methods within three different approaches (temporal, functional and comparative) at three different detail levels (abstract, mid-level and concrete) as ranked from highest to lowest. The levels hint to the scope of the application; with the higher levels indicative of larger scopes. In addition, the levels correlate with the expertise and familiarity of the risk analyst with the facility. Analyses at the lowest level require more so system familiarity than expertise and are best conducted by the facility owner. Analyses at the highest level require more expertise than familiarity and are best suited for the expert. (Expert here refers to an outside consultant who is knowledgeable in assessment methods but unfamiliar with the target system. Owner refers to someone who is not knowledgeable in assessment methods but is familiar with the target system.)

Following definitions from Campbell and Stamp, 2004, A temporal method stresses a system through the actual application of tests. These “tests” exercise key components of attacks, subject to some explicit or implicit constraints. The performance of the system as a consequence of the application of those tests is the result of the method. Where it is impractical to apply the tests to the system itself, a model of the system may suffice. The functional approach focuses on threats and protections. A threat model, a list of vulnerabilities, and the likelihood of success of the threats against the vulnerabilities are weighed against the assets, protections, and the likelihood of success of the protections against the threats. The comparative approach presents an explicit standard. An owner compares the owner's system and/or procedures with the standard. Note that there is no explicit system model involved here as there is in the temporal approach. Neither is there an explicit list of threats and assets here as there is in the functional approach.

An engagement consists of experts looking for any way, within given bounds, to compromise assets. An exercise links experts and owners together in order to test the protection on assets particular to a given system. Compliance testing is a more formal way of describing "door rattling." The tests included in methods of this type are such that the owner can execute them himself without the aid of an expert. A sequence method type consists of a series of steps, usually posed as questions, and sometimes in a form as complicated as a flowchart. An assistant method type keeps track of combinations of lists such as threats, vulnerabilities, and assets. A matrix method type is a table lookup. A principles method type, like all of the comparative types, is a list. A best practice method type is a list but it is more specific than a principles list. An audit method type is a list but it is more specific than a best practices list.

Scant classification methods existed prior to Campbell and Stamp, 2004. They include a bifurcation scheme into quantitative versus qualitative methods. AS/NZS 4360, 1999, adds a third element to the scheme, making it quantitative vs. semi-quantitative vs. qualitative. Another example classification scheme is von Solms' traditional assessments vs. baseline controls. BS 7799, 1999, is an example of a baseline control. These classifications did not offer much insight into method selection. The paragraphs that follow review some known conceptual risk assessment models.

		Approach		
Level		**Temporal**	**Functional**	**Comparative**
3	Abstract (Expert)	Engagement Red Team (e.g., IDART™)	Sequence AS/NZS 4360 FIPS PUB 191 IAM IEC/ISO TR 13335 Jelen Kaplan & Garrick NIST 800-30 Schneier	Principles CoCo Freudenburg GAISP GAPP OECD
2	Mid-Level (Collaborative)	Exercise Force on Force Penetration Testing	Assistant Manello OCTAVE RAM-W VSAT™	Best Practice DOE's 21 Steps e-Commerce ISF ITIL LfLO NIST 800-53 PoLO
1	Concrete (Owner)	Compliance Testing security scripts (e.g., SATAN, Nessus) "door rattling"	Matrix AMSA CRAMM RiskWatch SSAGT	Audit BS 7799 CobiT® SSAG Trust Services

Table 2 Example Classification
Source : Campbell and Stamp, 2004

Proposed Conceptual Framework

The derivation of a conceptual framework for risk analysis reveals all its dimensions and affords an exhaustive account of threats and assets. Fig. 1 presents an overall schematic of the relationship of **risk** to its ***four dimensions*** (the environment/community, the humans, the management, and the threat) as outlined in this study and as inspired by the works of Quarantelli, 1980, on disaster evacuations. The framework uses two distinct domains: that of the inherent global variables, which describe pre-existing information; and that of the local variables, which provide the basis for how an individual or a group reacts to a specific threat. The global community includes all initial variables of the evacuation—those that are not affected by any kind of pedestrian or management behavior once the evacuation starts. This information is to be taken from chronicled data and from emergency management agencies.

The global domain has two main components: the community and the threat itself. The community encompasses the physical environment, the persons and organizations that evolve within this environment, including its government, and outside entities such as nearby systems that may impact the course of events. The threat component represents the physical effects of the threat and is linked to location, evolution, and physical characteristics.

The community is characterized by a social climate, inherent social links, and numerous assets. The social climate, according to Quarantelli (1980), consists of the social, psychological, political, economic, legal, or historical factors which can affect the evacuation process. Included in this aspect of the model are the demographics of the humans evolving within the community, such as health and financial status.

Various social links, or bonds, tie community individuals to each other. Johnson, Feinberg and Johnston, 1994, document primary, secondary or nested secondary social groups. Primary and secondary groups contain members with primary (spousal, friendship, familial) and secondary ties, respectively. Strong bonds relate primary group members whereas secondary groups constitute more loosely knit social organizations, such as those made up of co-workers or fellow travelers in a tour group. Nested secondary groups embed members holding primary ties with members holding secondary ties and vice versa. For instance, a husband and wife pair forms a nested secondary group together with a vacationing tour group. Included within the global community are the material and conceptual assets/resources available to organizations and individual or groups of humans (Quarantelli, 1980, 1984, Perry, 1994.)

The local domain concerns itself with the actual onset of the threat, the ensuing actual resiliency and actual exposure consequences, the actual and perceived risk, and the end behavior. The global domain bears physically, socially and psychologically on the humans, delineating the local variables, resiliency, exposure, risks and behavior. Whereas the global variables define how a human can potentially react to a threat, it is the local variables that affect real-time or actual behavior.

Material and conceptual assets help enhance the community's preparedness and resilience, or its ability to cope with the threat. It is these available assets that form the basis for the population's vulnerability as the threat unfolds. Hence, the actual resiliency of the evacuees closely relates to the resources that are available through the global domain, including the proximity to evacuation routes. The actual exposure consequences can be interpreted as varying with the intensity of, and proximity to, the threat and the protection that is afforded.

It is the interaction of the actual exposure consequences and the actual resiliency that forms the actual risk inherently posed by the hurricane situation. This variable is a function of the probability of harm and the magnitude of the damage. The actual risk drives the individual (perception) and social (communication, coordination) processes that define the perceived risk. The evacuation behavior ensues from the perceived risk. Drabek's findings suggest that those who develop high levels of perceived personal risk tend to react significantly faster than others (Drabek, 1996).

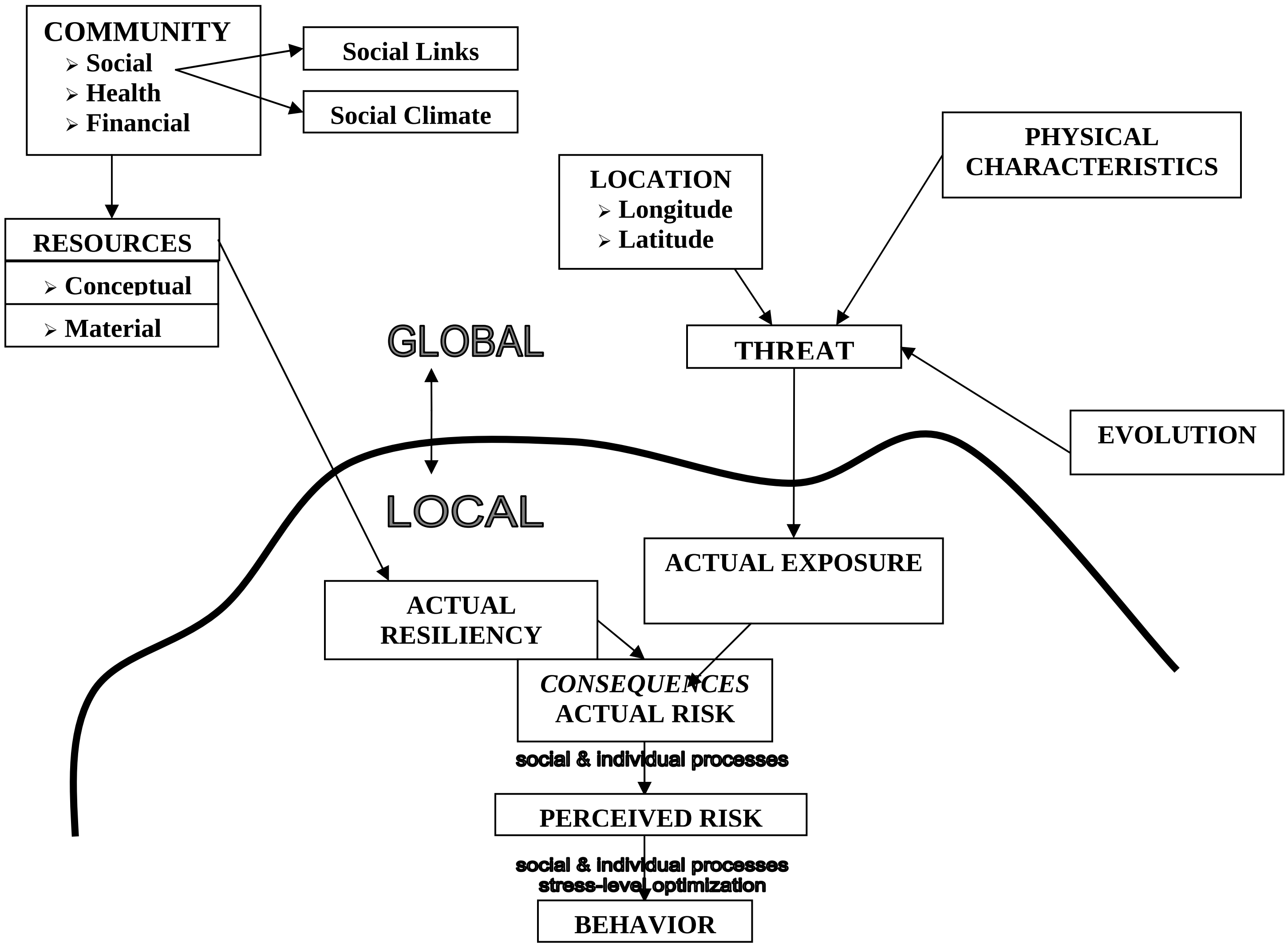
The EPA recommends the following conceptual framework for assessing and enhancing system vulnerability against the unwanted outcome of a terrorist or other intentional attack intended to substantially disrupt the ability to provide a safe and reliable supply of drinking water: 1) the characterization of the water system, including its mission and objectives, 2) the identification and prioritization of adverse consequences to avoid, 3) the determination of critical assets that might be subject to malevolent acts that could result in undesired consequences, 4) the assessment of the likelihood (qualitative probability) of such malevolent acts from adversaries, 5) the evaluation of existing countermeasures, 6) the analysis of current risk and development of a prioritized plan for risk reduction. With regards to item 2 above, Sandia Laboratories suggests that water systems, in general, are vulnerable to four broad classes of attacks: chemical contamination, biological contamination, physical disruption, and disruption of the computerized control network known as the SCADA system. Typical undesired events for water supply, treatment, and distribution may include power loss, system control loss, water supply contamination, and distribution loss.

The EPA recommended that a CWS reviews the potential for tempering or damaging its infrastructure in complying with the Bioterrorism Act. Elements of the infrastructure cited include: the pipes and constructed conveyances, the physical barriers, the water collection (pre-treatment and treatment), the storage and distribution facilities, the electronic (computer or other automated systems utilized), the use, storage and handling of various chemicals, the operation and maintenance of such systems.

Historically, the National Response Center (NRC), in *1983*, specified the major steps of risk assessment as the following: 1) hazard identification, 2) dose response, 3) exposure assessment, 4) risk characterization and 5) risk management. Later work by NRC, 1994, emphasized the iterative nature of incident management, and 1996, the importance of involving the stakeholders in mitigation policies.

Ezell quantifies the vulnerability, defined as a measure of system susceptibility to threat scenarios, of a medium clean sized water system using the Infrastructure Vulnerability Assessment Model (I-VAM). I-VAM is a multi-attribute value model, which scores and ranks the vulnerability of individual water system components. The functional decomposition of a clean water system follows research by AWWA (2002), which cites six subsystems and 14 components. The subsystems include: the source, the transmission, the treatment, the storage, the distribution, and the control. The source includes two (2) components (river and well), the transmission three (3) components (pump station, pipelines, valves), the treatment two (2) components (facilities and processes), the storage three (3) components (clearwell, tank, reservoir), the distribution three (3) components (pump station, delivery piping system, service piping system) and the control one (1) component (SCADA). Ezell fails to consider the use, storage and handling of chemicals as requested by the EPA. However, the approach utilized easily lends itself to the incorporation of this factor.

The model uses as attributes: deterrence, detection, delay, and response. Four value functions, established by subject-matter expects, measure the protection afforded by each decision attribute. Deterrence includes all implemented measures that are perceived by adversaries as too difficult to defeat (Garcia, 2001). Detection aims to detect unauthorized actions through sensing, and to inform the control center of the same. Delay is the time during which adversary penetration is impeded (Garcia, 2001). Response is the time necessary to respond to a threat (Garcia, 2001). The weights applied to the attributes, in determining the vulnerability of each component, were also established by subject-matter expects. Moving up the hierarchy from the component level to the subsystem level, or from the subsystem level to the system level, higher level scores are determined by a weighted average of the lower level scores achieved.



COMMUNITY
Social
Health
Financial
Social Links
Social Climate
RESOURCES
Conceptual
Material
LOCATION
Longitude
Latitude
PHYSICAL CHARACTERISTICS
GLOBAL
THREAT
EVOLUTION
LOCAL
ACTUAL EXPOSURE
ACTUAL RESILIENCY
CONSEQUENCES
ACTUAL RISK
social & individual processes
PERCEIVED RISK
social & individual processes
stress-level optimization
BEHAVIOR

Selection of Risk Assessment Methods

The review of the known classification schemes and conceptual frameworks for risk assessment has led to valuable insights into the optimal selection of a method for a given facility. The classification scheme proposed by Campbell and Stamps, 2004, lends itself to a selection scheme. Already, the levels of this classification were assigned by the original authors to specific assessments based on the level of expertise or familiarity of the study conductors. The assignment of the varied approaches remains unsettled.

The imposition of design analysis standards/codes, as done with comparative risk assessments, to ensure safety/security/surety has proven detrimental in fire safety engineering by stifling/limiting design creativity (Meacham, 1996). Hence, the recent move toward performance-based design analyses, which minimize the use of prescriptive design constraints. A similarity can be established between performance-based design analyses and temporal risk assessment. The both entail flexibility in design given that performance criteria are met. Previous observations suggest that temporal studies are best suited for innovative and complex designs, whereas comparative studies are best suited for the more common and mainline designs.

Collection of Risk Assessment Data

According to Sandia Laboratories, literature searches that cover the past 100 years reveal very few malevolent attacks on the water infrastructure in the United States. The information that is available is thus of limited use to predict the types of attacks that might be perpetrated in the coming years. Hence, the need for a conceptual framework that creates an exhaustive list of the potential threats and assets to consider in vulnerability or risk assessments.

According to the National Plan for Research and Development in Support of Critical Infrastructure Protection, 2004, the evaluation of threats and their likelihood is drawn from multiple sources of information and analysis of different types of threats and potential attackers.

Conclusions

This article presents a review of classification schemes and conceptual frameworks for assessing risk or vulnerabilities at water resource and other facilities. Based on the review, it derives guidelines for selecting risk assessment methods. The guidelines build on previous work by Campbell and Stamp, 2004, of Sandia Laboratories. Latter work selected methods based on the level of expertise, in risk assessment, and the level of familiarity, with the facility, of the analyst. This selection scheme was extended to reflect the design flexibility afforded by the methodological approach in assessing risk. Performance-based methods, such as the temporal and functional methods, which tolerate variations in design, are better suited for innovative and complex system designs. Those, such as the comparative methods, which promote rigid design standards, suit best the facilities with commonly encountered designs.

References

Aho, A. V., R. Sethi, J. D. Ullman, “Compilers: Principles, Techniques, and Tools.” Addison-Wesley. Reading, Massachusetts. 1986.

Alberts, C. J. and A. J. Durofee, “An Introduction to the OCTAVESM Method.” http://www.cert.org/octave/methodintro.html.

Alexander, C., S. Ishikawa and M. Silverstein, A Pattern Language: Towns, Buildings, Construction. Oxford University Press. 1977. ISBN 0-19-501919-9.

AMSA, “Asset Based Vulnerability Checklist for Wastewater Utilities ©.” January 2002.

AS/NZS 4360:1999 Risk Management.

BS 7799-1:1999 Information security management—Part 1: Code of practice for information security management. BS 7799-2:1999 Information security management—Part 2: Specification for information security management systems.

Campbell, P. L. and J. E. Stamp, “A classification Scheme for Risk Assessment Methods.” Sandia Laboratories, IORTA Publications, SAND2004-4233, Albuquerque, New Mexico, 2004.

Cazemier, J. A., P. L. Overbeek and L. M. C. Peters, “Best Practice for Security Management.” The ITIL Infrastructure Library. Office of Government Commerce (OCG). 1999. ISBN 0 11330014 X.

Checkland, P., Systems Thinking, Systems Practice. John Wiley & Sons, 1993.

CobiT 3nd Edition: “Control Objectives for Information and Related Technology (CobiT).” 3rd Edition. July 2000. Published by Information Technology Governance Institute (ITGI). ISBN 1-893209-13-X.

CoCo: Criteria of Control Board. The Canadian Institute of Chartered Accountants. “Guidance on Control.” November 1995. ISBN 0-88800-436-1.

CRAMM: UK Government Risk Analysis & Management Method. Insight Consulting. http://www.insight.co.uk/index.htm.

Department of Energy (DOE), “21 Steps to Improve Cyber Security of SCADA Networks.” (citation unknown)

e-Commerce Security – Enterprise Best Practices. Information Systems Audit and Control Foundation (ISACF). ISBN 1-893-209-10-5.

FIPS PUB 191. “Guideline for the Analysis of Local Area Network Security.” November 9, 1994.

Fried, S. D., “Penetration Testing.” Chapter 15 of the Information Security Management Handbook. Fifth Edition. Tipton & Krause, editors. Auerbach Publishers. Boca Raton, Florida. 2004.

Freudenburg, W. R., “Risky thinking: facts, values and blind spots in societal decisions about risks.” Reliability Engineering and System Safety 72 (2001), pp. 125-30.

GAISP: Information Systems Security Association (ISSA), “Generally Accepted Information Security Principles.” GAISP V3.0. www.gaisp.org.

GAPP: Marianne Swanson, Barbara Guttman, “Generally Accepted Principles and Practices for Securing Information Technology Systems.” NIST Special Publication 800-14, September 1996.

Gouldby and Samuels, “Language of Risk: Project Definitions”. FLOODsite Report T34/04/01, http://www.floodsite.net, 2005.

Hamill, J. T., R. F. Deckro, J. M. Kloeber Jr., T.S. Kelso, “Risk Management and the Value of Information in A Defense Computer System.” Military Operations Research, V7 N2 2002, pp. 61-81.

Hare, C., “Firewalls, Ten Percent of the Solution: A Security Architecture Primer.” Chapter 121 of the Information Security Management Handbook. Fifth Edition. Tipton & Krause, editors. Auerbach Publishers. Boca Raton, Florida. 2004.

IAM: “INFORMATION ASSESSMENT METHODOLOGY. INFOSEC ASSESSMENT METHODOLOGY COURSE. INFOSEC ASSESSMENT TRAINING AND RATING PROGRAM.” from www.nsa.gov.

Information Design Assurance Red Team (IDART™) at Sandia National Laboratories. http://www.sandia.gov/idart.

ISF: Information Security Forum, “The Standard of Good Practice for Information Security.” Version 4.0. March 2003.

ISO/IEC TR 13335 Information Technology--Guidelines for the management of IT Security.

Jelen, G. F., “A New Risk Management Paradigm for INFOSEC Assessments and Evaluations.” Computer Security Applications, 11th Annual Conference. 1995. pp. 261-7.

Kaplan, R., “A Matter of Trust.” Chapter 61 of the Information Security Management Handbook. Fifth Edition. Tipton & Krause, editors. Auerbach Publishers. Boca Raton, Florida. 2004.

Kaplan, S. and B. J. Garrick, “On the Quantitative Definition of Risk.” Risk Analysis, Vol. 1, No. 1, 1981, pp. 11-27.

LfLO: GAO/AIMD-98-68 Information Security Management. (US General Accounting Office Accounting and Information Management Division, “Executive Guide. Information Security Management. Learning From Leading Organizations.”) May 1998.

Manello, C. and W. Rocholl, “Security Evaluation: A Methodology for Risk Assessment.” IS Audit and Control Journal. Vol 6, pp. 42-6. 1997.

Meacham, B. J. The evolution of performance-based codes and fire safety design methods, NIST-GCR-98-761, National Institute of Standards and Technology, Gaithersburg, MD, 20899.

Muncaster, G. and E. J. Krall, “An enterprise view of defensive information assurance.” Milcom 1999: IEEE Military Communications Conference Proceedings, Atlantic City, NJ, pp. 714-8.

NIST 800-30: Stoneburner, G., A. Goguen and A. Feringa, “Risk Management Guide for Information Technology Systems.” NIST Special Publication 800-30. October 2001.

NIST 800-53: Ross, R., G. Stoneburner, S. Katzke, A. Johnson and M. Swanson, “Recommended Security Controls for Federal Information Systems.” NIST Special Publication 800-53. “Initial Public Draft.” October 2003.

OECD, “OECD Guidelines for the Security of Information Systems and Networks — Towards a Culture of Security.” Paris: OECD. July 2002. www.oecd.org.

Office of the Press Secretary, “Homeland Security Presidential Directive 7 (HSPD-7): Critical Infrastructure Identification, Prioritization, and Protection”. White House, Washington, D.C., 2003.

PoLO: U.S. General Accounting Office (GAO), “Information Security Risk Assessment: Practices of Leading Organizations.” Exposure Draft. GAO/AIMD-99-139. August 1999.

RAM-W: “Risk Assessment Methodology for Water Utilities,” Second Edition. Awwa Research Foundation. Denver, Colorado. 2001.

RiskWatch, “How to do a Complete Automated Risk Assessment: A Methodology Review.” AWhite Paper available at www.riskwatch.com.

Schneier, B., “Beyond Fear: Thinking Sensibly About Security in an UncertainWorld.” Copernicus Books, New York. 2003. ISBN 0-387-02620-7.

Security, Research and Business, 14-16 May 1997, Copenhagen, Denmark. pp. 91-98.
[43] VSAT™ Users Page: http://www.vsatusers.net/.

Skoudis, E., “Hacker Tools and Techniques.” Chapter 10 of the Information Security Management Handbook. Fifth Edition. Tipton & Krause, editors. Auerbach Publishers. Boca Raton, Florida. 2004.

SSAG: Swanson, M. “Security Self-Assessment Guide for Information Technology Systems.” NIST Special Publication 800-26. November 2001.

SSAGT: Pacific Northwest Laboratories, “Safeguards and Security Survey and Self-Assessment Guide and Toolkit.” (This material is available from PNL on a CD by calling (509) 375-4349.)

Stamp, J., J. Dillinger and W. Young, Sandia Laboratories, IORTA Publications, SAND2003-1772-C, Albuquerque, New Mexico, 2003.

Trust Services: American Institute of Public Certified Accountants (AICPA), Canadian Institute of Chartered Accountants (CICA), “Suitable Trust Services Criteria and Illustrations.” 2003. www.aicpa.org.

Von Solms, R., “Can Security Baselines replace Risk Analysis?” IFIP TC 11 Conference on Information.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	6	0	0	0	6
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	7	0	0	0	7

Notable Awards and Achievements

One of the important achievements accomplished during this period was the publication of two newsletters. This is the first time that the RI Water Resources Center has published a newsletter. The newsletters were invaluable in highlighting the research accomplishments of the center.

Publications from Prior Projects

None