Fact Finding Mission to Tsunami Affected Areas to assess impacts on Groundwater Resources

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1. Introduction

During February 11-18, 2005, a team of scientists sponsored by the US National Science Foundation (NSF) visited Sri Lanka to assess the impacts of tsunami on groundwater resources in the island's coastal zones. The team consisted of Professor Tissa Illangasekare of Colorado School of Mines, Professor Charles Harvey of MIT, and Dr. Jayantha Obeysekera from the South Florida Water Management District.

During the visit, the team met and/or interacted with managers, scientists, engineers, academicians, and filed personnel from the following agencies and universities:

- Hon. Prime Minister's Office
- Task Force for Rebuilding the Nation (TAFREN)
- Water Resources Board
- National Water Supply & Drainage Board
- Central Environmental Authority
- Department of Irrigation
- Industrial Technology Institute (ITI) (formerly CISIR)
- National Science Foundation of Sri Lanka
- University of Peradeniya
- South Eastern University
- University of Ruhuna
- International Water Management Institute (IWMI)

The team visited several locations affected by tsunami in the east and the south and surveyed numerous water supply wells and damage to infrastructure. The following is a brief report of the team's observations and recommendations for follow-up activities, the first phase of which is the organization of an information exchange workshop to be held in Sri Lanka in the summer

2. Groundwater Supplies in Coastal Areas affected by Tsunami

The residents in the coastal communities in tsunami-affected areas depend on either pipe-borne municipal utilities or dug wells for water supply for domestic use. Although National Water Supply and Drainage Board has recently increased coverage of pipe-borne water supply in many areas of the coast, the primary source of domestic water supply for many residents is still the private wells in their own backyard. Even if residents receive water from municipal utilities, they still maintain and use dug wells for washing, bathing and other uses. The most common source for municipal water supply in the island is the surface water from rivers and streams. However, in areas where surface water is not available or scarce, deep tube wells are the primary source for municipal water utility systems.

The tsunami has caused physical destruction of some infrastructure associated with a few of the municipal water supply schemes in the coastal belt. However, a bigger concern is the destruction of dug wells near the coast and the contamination of the private wells of residents who depend on them for domestic water supply.

The following observations were made from the field visits and the discussions with residents, engineers and scientists from the officials from the National Water Supply and Drainage Board and the Water Resources Board:

- Most of the private dug wells still appear to be contaminated with salt water. The contamination could have occurred due to one or more reasons. Two primary ways are:
    - Filling of wells with salt water associated with the flood waves of the tsunami.
    - Contamination of the coastal aquifers due to infiltration of stagnant salt water in the flooded lands. In most cases stagnation of water is due to poor drainage in coastal regions.
- Many governmental and non-governmental organizations have attempted to clean thousands of private dug wells by pumping out salty water in the wells, often multiple times. In many cases, the complete dewatering of the well has resulted in wall collapse making it unusable. Also, it appears that the water pumped out of the well into the adjacent lands may have simply re-percolated through the sandy soils resulting in re-introduction of salty water into the wells.
- National Groundwater Association has published a very generalized guide on well cleaning in tsunami affected areas (http://www.ngwa.org/pdf/welldisinfection.pdf). However, the utility of these guidelines under certain local conditions is questionable. For instance, excessive pumping in coastal areas may exacerbate the saltwater intrusion problems and cause cross contamination from adjacent septic tanks.
- We observed several wells with concrete casings simply tilted, destroying the well, presumably due to the shear force of tsunami waves traveling onshore and collapsing of the soil foundation.
- Based on the observation we made, salinity in private wells seem to have reduced significantly but still above 1-2 ppt. This water is not suitable for drinking but the residents in the coastal regions seem to use it for other domestic purposes such as bathing and washing. It is not clear how long it will take for the wells to be cleaned by natural recharge of fresh water during the rainy season.
- Contaminated wells not used by the public appear to be stratified in salinity with high salinity near the well bottom. Wells used by public for bathing and washing appear to be well mixed with little or no stratification.
- Some camps for Internally Displaced Personnel (IDPs) are located in areas where groundwater supplies are scarce. Currently, the water is being brought by trucks that is not practical or viable as a long-term solution. In one of the camps we visited where a well drilling operation was in progress, the geologists estimated a yield of 5 L/min that is inadequate to supply the camp.
- The density of population in the coastal belt is very high with very little land in between houses. Typically, each house has a dug well and a septic tank located not very far from each other causing concerns of cross contamination even before the tsunami. A carefully planned

monitoring effort is needed to investigate this cross contamination issue, particularly in view of proposed plans for relocating coastal residents.

- Some anecdotal information regarding unusual events attributed to the Indonesian earthquake and the associated tsunami waves have been reported. Some of them were:
  - Reports of water gushing out of the ground in the interior regions in advance of tsunami waves.
  - Reports of excessive sloshing of water in wells in an interior location far away from the coastal region.
  - Report of an increased yield in a well at an interior location.
- If the dug wells in the coastal regions continue to be unusable for some time, it may impose significant pressure on pipe born water supplied by surface water resources in the region.
- There is very little technical information about the groundwater resources in the coastal regions affected by tsunami. Although a general map of the geology of these regions exists, very little useful information regarding the local geology and the aquifer characteristics exist. The water level data is very scarce and there is no national network for monitoring of ground water levels and quality.
- Although much of the road-side debris has been cleared, many demolition debris remain in areas away from the highways. This debris may contain harmful substances, which may further contaminate the groundwater supplies in the coastal regions.
- Water Resources Board provided a possible conceptual model of how the tsunami may have contaminated coastal wells -- seawater infiltrated in the flooded zone, much of it inland where it was trapped and remained ponded for several days (see figure below). The saline water then migrates back towards the coast with regional groundwater flow.

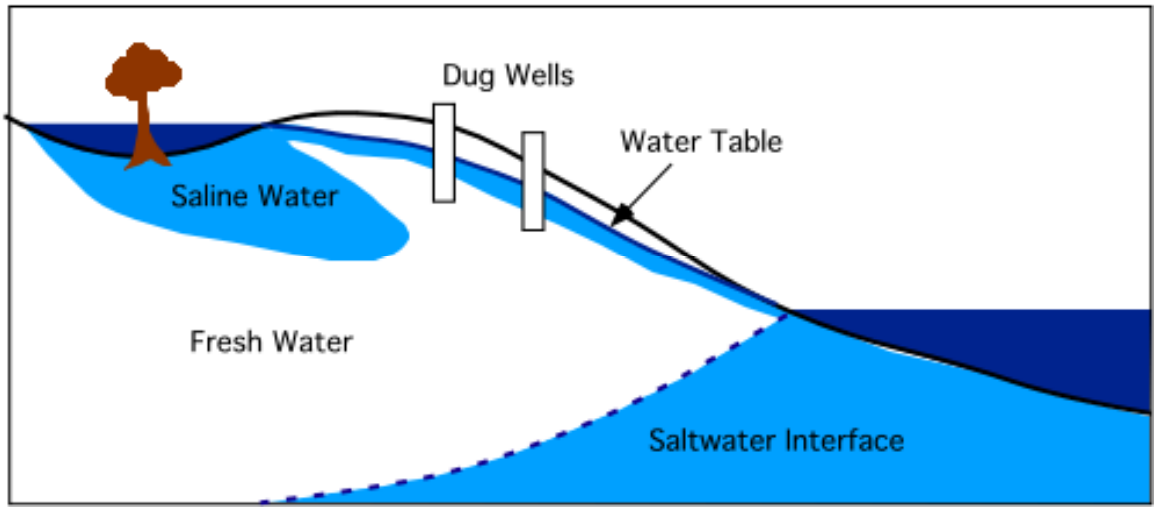


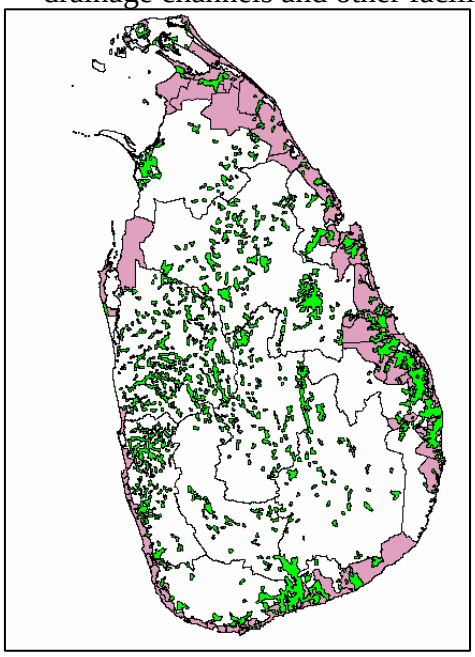
Figure 1. Conceptual model of well contamination due to the migration of saltwater front associated with interior flooding

3. Impact of tsunami on Coastal Agricultural Lands and Natural Vegetation

3.1 Paddy fields and highlands

As shown in the map (Figure 1) of paddy cultivated areas for Sri Lanka along with the affected geographical divisions, many paddy fields located in the eastern and southern Sri Lanka have likely been impacted severely by the tsunami waves. According to an excellent study conducted by the Mapa et al (2005), about two weeks after the tsunami event in the Ampara region, the crop lands, including the paddy fields near the coast, as well as vegetable groves in the adjacent highlands have been impacted due to one or more the following effects:

1. Physical destruction of crops due to tsunami waves moving inland.
2. Soil erosion and deposition on debris in the crop lands.
3. Prolonged inundation of crop lands with salt water due to the destruction or blockage of drainage channels and other facilities after the event.



4. Salinity in soils and the possible destruction of aggregate structure due to intrusion of salt water.

Mapa et. al (2005) monitored salinity soils within the root zone (up to 30 cm) at different distances from the shoreline up to about 1 km. They also monitored the salinity of standing water. A brief summary of their findings:

- Soil salinity, as measure by Electrical Conductivity (EC) of the lands unaffected by the tsunami was about 0.04 decisemens per meter (dS/m). However, the EC values of the affected paddy lands were 20 to 200 times higher, with salinities at high values even after heavy rains.
- The soil salinities in these areas may sustain for a prolonged period of time due to poor drainage and high evaporation.
- Well water in the region contained high salinity. They cannot be used for any domestic or agricultural purposes.

Mapa et. el (2005) emphasized the urgency of reclaiming paddy lands, mapping of affected areas, and importance of having a national focus on this issue with input from stakeholders, farmers, soil scientists, extension officers and engineers.

3.2 Natural Vegetation

At many locations in the areas visited, the team observed the impact of tsunami waves on natural vegetations all along the costal belt. Except for the salt tolerant coconut trees, many other trees appear to be dying. However, there were indications that heavy rains following the tsunami in some areas appear to have helped recover some of the dying trees. In other areas, it is not clear if the trees continue to be impacted by the contaminated groundwater.

4. Needs Assessment

The following problems need to be addressed:

<u>Short Term:</u>

- Extent of the saltwater contamination in an around private dug wells needs to be assessed. Also, the amount of time it will take to recover the wells to pre-tsunami conditions needs to be estimated.
- Current methods of well cleaning using complete dewatering need to be re-evaluated? Proper well cleaning procedures that account for local geology and soils must be developed. The methods should include, but are not limited to:
    - Drawdown of the well during a single pumping cycle
    - Discharge locations and criteria for distance away from the well
    - Pumping frequency
    - Test criteria
- The severity of the contamination of the coastal aquifer needs to be assessed. The following need to be addressed:
    - Was the contamination of the costal aquifer due to infiltration of saltwater in sandy soils along the coast?
    - What was the extent of pre-tsunami saltwater intrusion? Did tsunami exacerbate the saltwater intrusion along the coast, particularly in drought-prone areas?
    - Is there a plume of saltwater in the unsaturated zone? How fast does it migrate?
    - Does the well cleaning through pumping accelerate the migration of the plume into the wells being cleaned?
    - Did inundation of coastal belt remain long enough for saltwater to fill the unsaturated zone? The answer largely depends on the vertical hydraulic conductivity of the soil.
    - Is the saltwater mixing, perhaps due to density instabilities, with the underlying freshwater?
    - Has the saltwater geochemically interacted with the sediment?
    - How have well purging efforts affected the salinity distribution in the aquifer?
    - In densely populated areas near the coast, was groundwater contaminated with Coliform bacteria due to presence of septic tanks near wells? Did tsunami exacerbate this contamination?
    - What is potential contamination of coastal aquifers due to tsunami debris?
- Immediate assessment of water availability for existing and/or new camps of Internally Displaced Personnel (IDPs) and relocated towns is needed.
- Training and public awareness campaigns for dealing with private dug wells contaminated by saltwater
- Mapping and immediate monitoring of paddy fields and highland croplands affected by the tsunami
- Mapping and immediate monitoring of natural vegetation in the coastal belt. In particular, the following questions needs to addressed:
    - Are most trees dying due to temporary inundation of salt water and poor drainage or is it due to the continued contamination of the aquifer.
    - If the same types of trees (eg. Mangos) will they survive?

<u>Long Term</u>

- More emphasis is needed to evaluate and manage groundwater resources in the country with special emphasis on coastal watersheds.
- Unrestricted extraction of groundwater in coastal belts must be regulated through a permitting process

- A national database for geologic and hydrogeologic information need to be established. This will require the assembly of numerous geologic information collected through special studies into a well-designed database accessible by all agencies
- Basic GIS coverages of wells and their attributes (both tube wells as wells as large private dug wells, if possible) need to be prepared.
- Hazardous waste sites which may potentially contaminate the coastal aquifers need to be mapped and characterized.
- Spatial extent the rate of inland migration of the saltwater front in coastal belt need to be assessed.
- Integrated management of both surface and groundwater in coastal watersheds must be initiated through the development of basin plans for water supply.
- Computer modeling groundwater must be used a planning tool for planning and regulation of groundwater resources.
- Training in field data collection, computer modeling, and remote sensing is needed for professionals managing the groundwater resources.
- A national focus on the problem of soil salinity with emphasis on reclamation of lands affected by the tsunami and introduction of salt tolerant crops
- A comprehensive investigation of sustainability of natural vegetation in coastal belts affected by the tsunami

5. Recommendation

The team finds that the time available during this preliminary assessment visit was not adequate to obtain an in-depth understanding of all the issues and identify all science and engineering needs to address groundwater related problems associated with the tsunami. However, our preliminary findings suggest that the general problems of adequacy of water supply in Sri Lanka and actions that need to be taken to address the specific problems associated with groundwater are not limited to science and technology issues, but are also related to other inefficiencies in planning and management and the lack of research infrastructure, both in the local universities and in water agencies. Some of these are beyond the scope of what we propose and our recommendation will only focus on the science and technical issues and assistance we could provide to build the research and educational infrastructure in the Universities to address both short and long term needs to maintain clean and reliable water supply for the people of Sri Lanka.

The team strongly believes that the options that need to be explored should all have a strong component of collaboration between the US and local scientists. The options as we see are: (1) sharing data and information through workshops and conferences with the focus on tsunami effects on agricultural land, vegetation and water, (2) team of US water scientists and engineers with relevant background going to Sri Lanka for first hand assessment of the situation by visiting the affected areas and meeting with the local scientists and engineers, (3) joint preparation of research proposals to address both basic and applied scientific problems, (4) offer training courses and workshops on specific topics (e.g. modeling, integrated water management, field monitoring, groundwater exploration and well drilling etc.) to be held in Sri Lanka, (5) training and workshops on special science and technology topics to be held at US universities and water agencies (e.g. USGS, USBR) for participants from Sri Lanka and other tsunami

affected countries (5) faculty exchange programs jointly sponsored by US and local Universities, (6) student exchange programs for undergraduate students through summer internships and undergraduate research opportunities programs , and (7) graduate student exchange programs coordinated through funded research projects.

There are many cost and logistical implications and limitations associated with implementation of one or more of the options we have identified. With the currently approved funds, it will only be feasible to recommend few preliminary options. We propose a site visit by a panel of experts and holding information exchange workshop in Sri Lanka focusing on the needs that are identified in the previous section of this report. It is our expectation that the US panel will get the opportunity to explore other options that were listed and prioritize them and make recommendations to NSF on a plan of action. As a part of these recommendations, we will separately identify research topics that are fundamental in nature that could only be conducted in USA through more sophisticated analysis and experimentation, and research that are applied that should be undertaken by the local scientists. In addition, any preliminary recommendations the panel could make on management practices that the local water agencies could implement to mitigate the detrimental effects of the tsunami on land and water will be identified. The workshop will be followed by a public presentation organized in the form of a conference.

6. Management Plan for the Workshop

The proposed information exchange workshop will be held in Sri Lanka. The principal investigator will work with the NSF program officers to formulate a panel of US scientists to visit Sri Lanka taking into consideration the number has to be limited depending on the available travel funds approved by NSF. The panel composition will be determined based on the expertise needed to address the research and training needs that have been identified. We propose that the panel should include, at a minimum people with following expertise:

- Geohydrolgist with background and expertise in coastal groundwater conditions, saltwater intrusion and geochemistry.
- Surface/Groundwater hydrologist familiar with integrated management of surface and groundwater resources for urban, agricultural and environmental uses.
- Hydrologic modeling expert with a background in model development integrated modeling codes and application.
- Geophysicist or hydrogeolgist with expertise in fracture flow and fractured system characterization.
- Crop scientist or a plant ecologist with expertise on salinity effects on crops, plants and vegetation.
- Field hydrologist with expertise in monitoring, networking design and GIS/Remote Sensing.

Sri Lankan scientist and engineers who are familiar with the local conditions will be invited to participate and contribute to the workshop. These participants will make presentations on topics covering, current water supply situation in tsunami affected regions and future demands, geologic and hydrogeologic conditions, issues related to agriculture and irrigation, conditions specific to different regions affected by the tsunami (north, north-east, south, and south-west), existing research infrastructure, existing data and data gaps and university curricula in hydrology and water resources.

As many logistical issues need to be resolved prior to holding the workshop, at this time it will not be possible to further develop a firm management plan for the workshop. Once the local sponsoring agencies and universities have been identified, we will work closely with them to develop a management plan to make sure the efforts are kept on target to meet the goals as identified and agreed on. A preliminary plan is presented here for the purpose of organizing the panel visit and coordination of activities in Sri Lanka.

1. Dates and duration: We propose the workshop be held in the summer in June or July, 2005. The exact dates will be determined based on the schedules of US panel members and the key personnel of the local sponsors. We are expecting the panel to spend a minimum of 7 working days in Sri Lanka. This will include 3 days for field visits to selected locations in the affected areas that we have identified during our last visit and 4 days for the workshop and conference. We propose to hold the workshop in two parts. One will be held at a location central to the affected region, most probably in the North-East. The water supply problems are more critical in the north and north-east as groundwater is the only available source of water supply. It is our expectation that the panel will get the opportunity to obtain a first hand knowledge on the local conditions and interact with the local scientist, field researchers and water agency personnel in these regions. The second workshop will be held at a central location either in Kandy or Colombo where better facilities will be available and allowing easy access for the participation of personnel from research organizations, water agencies and Universities.

2. Workshop Format
   The focus of the first one-day workshop will be more on identification of problems and gather data specific to the region. This workshop will be open to any participant, but presentations will be requested from local experts who will be identified to cover specific topics. A list of topics will be developed based on the issues that have been identified in section 4 of this report. The goal is for the visiting US panel members to be educated on the problems, local conditions and data for them to get insights into how their expertise could be utilized.

   The second workshop will be organized more around needs related to scientific and engineering issues and building a research infrastructure. The participation of the workshop will be by invitation only to limit the numbers to make the information exchange informal, efficient and focused. We will work with the local agencies to identify the appropriate participants to cover the topics that are of relevance and importance. Specific instructions will be provided to the local participants to prepare material for the workshop. From the water agency participants, we will specifically request to present existing data, current data collection and monitoring schemes, available technologies for data collection and site characterization and discuss data needs. The participants from the research organizations (e.g, Universities, National Science Foundation of Sri Lanka Institute of Fundamental Studies, Industrial Technology Institute and International Water Management Institute) will be requested to focus on existing knowledge on relevant

areas of research and research needs. The University participants will be requested to present in addition to research related issues, the educational and training needs.

3. Conference

At the conclusion of the workshop, a conference will be held in Colombo. The goal is to present the preliminary findings to the public and the decision makers. We will invite the Minster of Science and Minster of Education. During our last visit, we made contacts with the Prime Minster's office and the Presidential Task Force for Rebuilding the Nation. It is our hope that the conference will receive the support and sponsorship from the highest levels of government to make it possible to purse follow-up activities and support for plan implementation.

The findings and the recommendations that will be developed in the workshop will be presented. A summary report will also be presented to the appropriate authorities in Sri Lanka.