Interactions between ground water and surface water in the Bogue Phalia near Leland, Mississippi, Summer 2007

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Ground-water discharge is a key control on streamflow quality and quantity and associated aquatic ecosystems; however, factors that affect the spatial and temporal distribution of water flux across stream beds remain poorly understood. The objective of this study is to characterize ground-water and surface-water interaction in the Bogue Phalia, which drains an agricultural area in northwestern Mississippi. Study sites are located near the Bogue Phalia gaging station near Leland, MS. At the study sites, the Bogue Phalia is about 35 meters wide with a maximum depth at low flow of 1.2 meters and a discharge of 78 cubic feet per second during the study period (June – August 2007). Ground-water discharge was measured with pan and bag seepage meters fitted with extensions for deployment in deep (>1 meter) water. Five arrays were measured across the width of the river, with an average of 10 meters between each array and at least 5 meters per array. Seepage data were supplemented with measurements of head gradient, hydraulic conductivity, bed sediment grain size, and temperature in order to better understand interactions between ground water and surface water. Drought conditions in the area were temporarily relieved by storms in late June and early July when flow in the river reached a maximum of 5,120 cubic feet per second. Measurements were made both before the storms and after flow in the river returned to base conditions in order to evaluate the effects of flooding on ground-water discharge.

Preliminary results indicate that the highest ground-water discharge fluxes occurred along the central axis of the Bogue Phalia; whereas, the lowest fluxes occurred along the banks. The main channel was gaining at the study sites, although losing reaches were common in ditch-like tributaries. The average and (standard deviation) of vertical flux through the study area was 1.2 x 10-6 meters per second (m/s) (6.3×10^{-7} m/s), and ranged from a minimum of 3×10^{-8} m/s to a maximum of 5×10^{-6} m/s. Techniques for setting seepage meters in deeper water produced an average coefficient of variation (COV) of 0.5, which is greater than the typical value for shallow water application (COV = 0.3). The mean flux before the storms in late June and early July is statistically indistinguishable from the mean after the storms. Although the maximum flux increased slightly from 4.2×10^{-6}m/s (2.7×10^{-6} m/s) to 5.6×10^{-6}m/s (1.8×10^{-6}cm/s) and shifted position by approximately 30 m upstream following the storm. The highest fluxes always occurred in areas where the stream bed was composed of medium- to coarse-grained sand, whereas the lowest fluxes occurred where the bed sediment was fine-grained, primarily along the banks and particularly downstream of a tributary. Seepage-meter studies elsewhere in the Southeastern United States have shown average ground water discharge fluxes of approximately an order of magnitude greater than those at the Bogue Phalia, an effect that could be due to either ground-water pumping or drought conditions.

Keywords: Agriculture, Water Quality, Surface Water, Management and Planning

student presenter

Introduction

The Bogue Phalia River is located in the Delta region of MS. The Delta is located in north western Mississippi and accounts for a large portion of agriculture that occurs in the state. Crops grown in the Delta include but are not limited to rice, soybeans and cotton. Agriculture in the Delta relies on the underlying Mississippi Alluvial Aquifer for the majority of its hydrologic needs. The aquifer is comprised of coarse-grained sand and gravel with inter-bedded layers of clay, silt, and fine-grained sand. Average thickness of the aquifer is 41 meters *(Kerry, 2001)*. A low permeability zone comprised of clay, silt and fine-grained sand occur on the surface of the aquifer. This material is known as the upper confining unit and has an average thickness of 8 meters *(Kerry, 2001)*. Pumping rates of 7500 liters per minute from the alluvial aquifer are common for wells in the Delta *(Kerry, 2001)*. Withdraws from the aquifer are greatest during the summer months when agricultural needs are highest. Heavy pumping of the aquifer creates a head differential around wells, which will affect the flow of groundwater to rivers occurring in the Delta. The aquifer discharges to rivers in the Delta during periods of low river stages and is recharged during high river stages. Farming practices combined with the low permeability of the upper confining unit cause excess runoff to rivers in the Delta during storm events.

Purpose

During the summer of 2007, a field project was conducted with the purpose of characterizing the spatial and temporal distribution of groundwater and surface water interaction in the Bogue Phalia River, MS. The work was funded by the USGS NAWQA Study that is also observing the Bogue Phalia River. Measurements of vertical groundwater flux were compared to fluxes observed at similar sites in other regions of the United States. Bed sediments were classified to evaluate their affects on groundwater discharge. Storm events during the project allowed for the evaluation of temporal changes in groundwater discharge caused by large flow events.

Field Site

A location roughly 800 meters south of the USGS Bogue Phalia #07288650 gauging station, along Mark Rd, was chosen as the main area of study (Figure 1). The river at this location was roughly 35 meters wide with a maximum depth of 1.2 meters. Depth in the river increased to the north and south of the field site. The stretch of the river was relatively straight and had a tributary joining the main channel directly to the East. The main channel of the river is positioned along the left bank through much of the Northern portion of the field site. The reduction of surface water velocity in the central portion of the river allows coarse-grained material to accumulate in this area. Coarse-grained sediment was also present in and directly adjacent to the main channel. Fine-grained sediment occurs along the banks and where the tributary joined the main channel. Thickness of the fine-grained sediment on the bed surface was 38 cm in areas directly down stream from the tributary. Flow in the river during the study period was typically 2.2 m^3/s. The river incised the surrounding flat-lying topography by approximately three to five meters at the field site. During field operations pumping for irrigation throughout the watershed created elevated (0.1-0.3 m) water levels in the river due to increased runoff. The river was bounded to the east and west by agricultural fields. Crop dusting of the adjacent fields occurred on a weekly basis through field operations. Conditions were hot and humid with afternoon thunderstorms occurring periodically.

Equipment

Vertical flux of ground water through the stream bed was measured using modified pan-and-bag seepage meters. Pan-and-bag seepage meters offer a convenient way to accurately characterize vertical groundwater flux in stream beds. Devices of this type typically consist of an inverted bucket or drum that is inserted into the stream bed. A collection bag is attached to the drum using a piece of tubing. The bag is weighed before and after attachment to the pan and the time the bag is allowed to fill is recorded. The vertical flux can be calculated using the area of the pan, the time elapsed, and the weight gain of the bag. The calculation is based on Darcy's Law:

$$\frac{Q}{A} = K\left(\frac{dh}{dl}\right)$$

(1) Where Q is the discharge, K is the hydraulic conductivity of the material, and $\left(\frac{dh}{dl}\right)$ is the hydraulic gradient and A is the cross-sectional areas through which flow occurs. To calculate the flux using seepage meters the evaluation of the following terms are made (Sanders, 1998):

$$\text{Vertical Flux Through Streambed} = \frac{Q}{A} = \frac{\text{Volume Seeped Into Bag}}{\text{elapsed time} \times \text{cross sectional area of pan}}$$

(2) Meters used in the study were constructed from inverted five gallon buckets that were equipped with a hydrodynamic carapace. The carapace prevents scouring of the bed sediments (Figure 2), which can create an increase in observed flux. The system utilizes a bag that is formed from 25 – μm – thick nylon and polyethylene

film. It has a maximum capacity of 3500 ml. A piece of 0.95 cm tubing is inserted through the inflation port of the bag and secured with waterproof tape. The tubing can then be attached to the pan. The bag is sold commercially as a packing material by Inflatable Packing Inc as a Void-Fill Bag *(Craig 2005)*. Bags are also enclosed in a rigid PVC shell. Shells are constructed of 0.16 cm PVC and measure 30 cm by 30 cm by 8cm. The shell eliminates the affect of velocity head on the bag. Water flowing over the bag creates a differential pressure between the bag and the surrounding water column (*Shinn et al, 2002 and Murdoch and Kelly, 2003*). This creates a condition where the total hydraulic head in the bag is less than that of the surrounding water column. Field observations and theoretical analysis by *Kelly (2001)* and *Murdoch and Kelly (2003)* determined this effect can cause a 5 – 10% increase in observed flux. The shell holding the bag is attached to the pan using a high-flow quick disconnect adapted with a true-union ball valve. These meters were originally designed by *Kelly (2001)*, *Kelly and Murdoch (2003)*, and *Murdoch and Kelly (2003)*. The meters were then refined to their current design by *Craig (2005)* to be used in shallow water (0.3 meters >= water depth).

Water depths that exceeded 0.5 meters created difficulties in pan installation and bag retrieval. Modifications were made to the original design to alleviate these problems (Figure 3). The top of the pan was mounted with a 1.27 cm threaded flange fitting. Varying length of 1.27 cm PVC pipe was then mounted to the top of the pan. This aided in insertion and removal of the pan from the stream bed. This technique also provided a way to identify the pan in deep or cloudy water. Bag retrieval was aided by removing the shell and bag directly from the pan. The pan was mounted with a bulk head fitting and barb attachment so 1.27 cm diameter clear plastic tubing could be attached to the shell. The shell containing the bag was attached to the tube using a true-union ball vale and barb attachment. Varying length of tubing could be used depending on the depth of water. The shell was prevented from sinking using a 0.63 cm PVC frame, which was mounted with pool floats. The frame allowed the shell to rest approximately 15 cm below the surface of the water.

Procedures

Seepage meters were placed at the field site along Mark Rd during two time events during the summer of 2007. The first complete set of measurements was made from June 12th, 2007 – June 18th, 2007. The set consisted of Craig designed and modified meters. Four arrays across the river were made, which can be seen as arrays two – five in Figure 4. Each array consisted of at least five pans with a minimum of three meters between each pan. There was a spacing of approximately 10 meters down stream between each array. The first array was located the furthest upstream as so not to disturb sediments in downstream locations. Pans were placed in the morning and allowed to equilibrate for at least 30 minutes. Bags were pre-filled with a minimum amount of water to help induce flow and then attached to the shells and weighed. The shells were then attached to the pans and left to collect. Measurement times varied but averaged 30 minutes. Shells were collected and then re-weighed to obtain weight gain (positive flux) or loss (negative flux). A series of five measurements were made from each pan to obtain an average flux at each location. Pans were removed from the river after each series of five measurements and moved down stream at least 10 meters for the next array.

On June 19th a severe storm hit the area. This was followed by another storm on July 7th. Maximum gauge height during these two events was 5.2 m and 6.6 m, respectively. Max discharge during these two events was 70 m^3/s and 160 m^3/s respectively (Figure 5). Conditions in the river were un-safe and field observations were halted. Work continued on July 20th when conditions in the river were similar to those seen before the storms.

The second set of measurements was made from July 20th 2007 – July 29th 2007 and consisted of only deep water modified seepage meters. The set consisted of five arrays that can be seen as arrays one through five in Figure 4. Each array consisted of least five pans with 3 meters between each pan. A spacing of 10 meters up or down stream was used between each array. The first array in the set was located in the middle of the study area and continued down stream. When conditions permitted the arrays were moved up stream. Longer measurement times produced less variation in the results during the first set. Therefore, measurement times with an average of 50 minutes were used during this set. Pans were installed in the mid-morning and allowed to equilibrate for 30 minutes. Bags were prepared and attached to shells and then attached to the pans in the same manner as the first complete set of arrays. Five measurements were made from each pan to obtain an average at each location. The pans were then left in place overnight without the bags. A second series of five measurements were then made from each location upon arriving to the river the next morning. An average of both series of measurements could then be made at each location. After the second set of measurement the pans were moved up or down stream 10 meters for the next array.

Seepage meters were also emplaced at the Fratesi Boat Ramp on MS Highway 82 on two occasions. The Fratesi Boat Ramp is approximately two kilometers north of USGS gauging station #07288650. The river has greater depths and is wider at this location than at the field site along Mark Rd. Sediment size and distribution are similar to those at the Mark Rd. field site. The first flux measurements were taken on June 11th, 2007 before the storm events. Fluxes were measured again on July 1st, 2007 after the first storm event but before the second. One array that consisted of at least 5 meters was made across the river during each set. Procedures for bag preparation, installation, and removal were the same as at Mark Rd.

In addition to flux measurements, core samples were taken along arrays 1 and 3 (Figure 4) at the field site. A total of six samples were taken, three along each array. Samples were taken from the left and right banks and the main channel of the river. Cores were taken after the storm events on August 10th 2007. Cores varied in length from 38 to 104 cm. Core samples were taken using schedule 20, 1.27 cm, PVC pipe. The cores were capped for storage before leaving the river and opened at a later time.

Results

During the first set of measurements at the field site along Mark Rd, the river was gaining at all locations measured. Average flux during the time period was 1.2×10^{-6} m/s. The measurements had an average standard deviation of 8.1×10^{-7} m/s. The highest flux measured was 4.0 x 10-6 m/s and had a standard deviation of 2.7×10^{-6} m/s. This flux was measured along array 5 in the central part of the river where the water depth was 0.8 meters (Figure 6). The lowest flux was 3.2 10^{-8} m/s and had a standard deviation of 6.6×10^{-8} m/s. This flux occurred on array 2 along the right bank of the river. Highest fluxes occurred in and along the edges of the main channel, as well as in areas where coarse-grained sediment was able to accumulate. Lowest fluxes were concentrated along the banks of the river, where the tributary joined the river, and directly downstream of where the tributary joined the main channel.

The second set of flux measurements produced results similar to those of the first set. The average flux during these measurements was 1.2×10^{-6} m/s. The measurements had an average standard deviation of 4.5×10^{-7} m/s. The highest flux during this set of measurements was 5.6×10^{-6} m/s with a standard deviation of 1.7×10^{-6} m/s. This flux occurred along array 2 in the central part of the river where the water depth was 0.3 meters (Figure 7). Surface water velocity in the river was lowest in areas directly west of this location, allowing a large area of coarse-grained sediment to deposit. The lowest flux during this set was 1.3×10^{-7} m/s and had a standard deviation of 8.4×10^{-8} m/s. This flux occurred along array 5 on the left bank directly downstream of where the tributary joined the main channel. The depth of the river was 0.27 meters at this location. Highest fluxes were concentrated along the edges of the main channel rather than in the main channel as in the first set. Lowest fluxes were still observed along the banks of the river and where the tributary joined the main channel. Areas directly down stream of the tributary had the lowest fluxes during both sets of measurements.

Measurements made on June 11th at the Fratesi Boat Ramp had an average flux of 4.5×10^{-7} m/s. The average standard deviation of these measurements was 5.1×10^{-7} m/s. Flux values during this set varied from 1.7×10^{-6} m/s to 2.4×10^{-8} m/s. The highest flux during this set occurred in the main channel of the river. The second set of measurements had an average flux of 2.6×10^{-7} m/s with little variation from the mean. The lowest flux in this set was 4.9×10^{-8} m/s and occurred along the right bank of the river. Both sets of measurements displayed a general trend of lowest fluxes occurring along the banks and highest in the central parts of the river.

Core samples taken from the river at the field site along Mark Rd identified four major soil types in the river (Figure 8) according to the Unified Soils Classification System. Soils occurring on the surface of the river along array one varied from SP (uniform, clean, coarse-grained sand) to SM (coarse-grained sand containing non-plastic fines). Sand layers varied in thickness from 38.1 cm (entire length of core) to 48.3 cm. Sand layers transitioned into SC soils (dirty, coarse-grained sand containing plastic fines) and then into CH (plastic, sticky, fines) soil types of an unknown thickness at the bottom of the cores. Cores along array three all had SM soil types occurring on the surface of the river bed (Figure 8). The cores varied in the thickness of sand with and had SC and CH lenses occurring within the sand layers. Average thickness of sand layers along array three was 84.7 cm. All cores along this array transitioned into CH soil types of unknown thickness at the bottom of the cores.

Conclusions

The mean flux before and after the storm (1.2×10^{-6} m/s) are statistically indistinguishable. There was more variation in the measurements before the storms than after the storms. After the storms, the highest flux moved position upstream approximately 30 meters but was still located along the edges of the main channel. The highest flux increased by 1.6×10^{-6} m/s. The highest fluxes before and after the storm occurred in areas where coarse-grained sediment occurred on the bed surface. The mean low flux is 5.8×10^{-8} m/s and varied by 5.2×10^{-8} m/s. During both measurements these fluxes occurred in areas of fine-grained sediment accumulation either on the banks of the river or directly downstream from where the tributary joined the main channel. The variation in the magnitude of groundwater flux may be contributed to a re-distribution of fine grained material between and after storms.

Core samples indicate that a layer of fine-grained material with an unknown thickness underlies the river under the majority of the field site. The hydraulic conductivity of this sediment is much lower than that of the coarse-grained material that occurs on the majority of the river bed. Depending on the extensiveness of this layer, it could act as a barrier to flow and reduce the flux of groundwater to the river.

The mean fluxes observed at the Bogue Phalia River are one order of magnitude lower than mean fluxes observed at four sites elsewhere in the United States. Allison Craig *(2005)* made measurements of groundwater flux at Maple Creek, Nebraska and Leary –Weber Ditch, Indiana as part of the USGS ACT program. Both sites had shallower water depths and were not as wide as the Bogue Phalia River. Sediment on the surface of the bed at both sites was coarse-grained. Fine-grained sediment occurred along the banks but was not identified at depths. Fluxes at Maple Creek had a mean of 1×10^{-5} m/s *(Craig 2005)*. Highest fluxes at this site occurred in the central parts of the river in coarse-grained sediment. Lowest fluxes occurred along the banks of the river in fine-grained sediment. Mean flux at Leary-Weber Ditch was 1×10^{-5} m/s *(Craig 2005)*. The highest and lowest fluxes occurred at the same positions and sediment types as in Maple Creek.

Katherine Stone and colleagues characterized groundwater flux at Eighteen Mile Creek, South Carolina as part of an undergraduate research program at Clemson University. The stream is narrower, shallower, and contains less fine-grained sediment than the Bogue Phalia. The average flux at Eighteen Mile Creek was found to be 6.46×10^{-6} m/s. Highest fluxes occurred in the central parts of the river with lowest fluxes occurring along the banks. Susan Kelly *(2001)* measured flux at Twelve Mile Creek, SC. Twelve Mile Creek is approximately ten kilometers north of Eighteen Mile Creek, SC and is similar in all aspects of the river. Mean flux in the river was 1×10^{-5} m/s with highest fluxes occurring in the center of the stream and lowest fluxes occurring along the banks.

The Bogue Phalia has the same general trend of ground water flux as seen in other rivers in the United States. The trend is for greatest fluxes to occur in the central parts of the river and lowest fluxes to occur along the banks. The trend is the same but fluxes are one order of magnitude lower than that of other rivers studied by Clemson research teams. Two possibilities may be attributed to the low fluxes observed at the Bogue Phalia River. The presence of a fine-grained material occurring in and below the river could act as a barrier to flow and effectively reduce the amount of ground water discharge observed. Reductions may also be attributed to groundwater pumping during the field experiment. The head differential in the water table caused by pumping of the underlying aquifer may direct flow away from the river when pumps are being used. Pumps were in use over 70% of the time during the field experiments.

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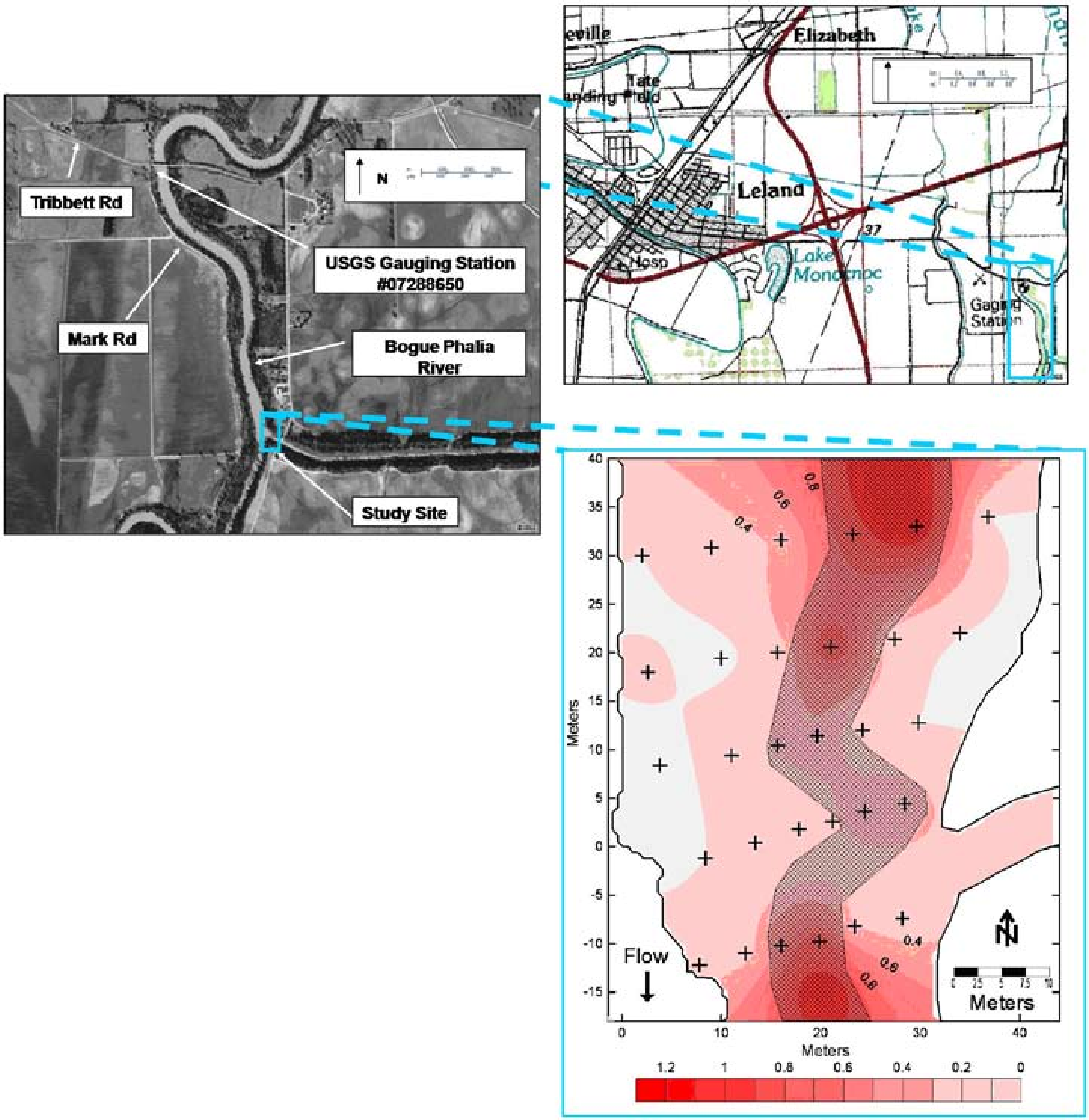

Figure 1. Road map and aerial photo of study area. Depth map of study area. The cross-hatch identifies the main channel of the river. Crosses indicate location of seepage meter measurements.

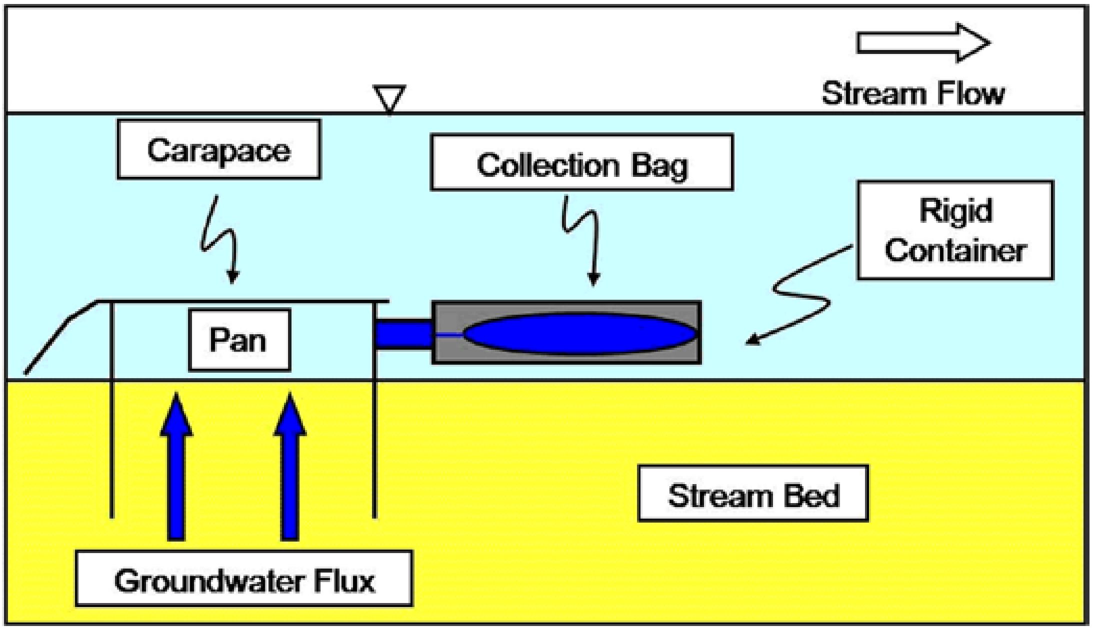

Figure 2. Cross sectional view of shallow water seepage meter.

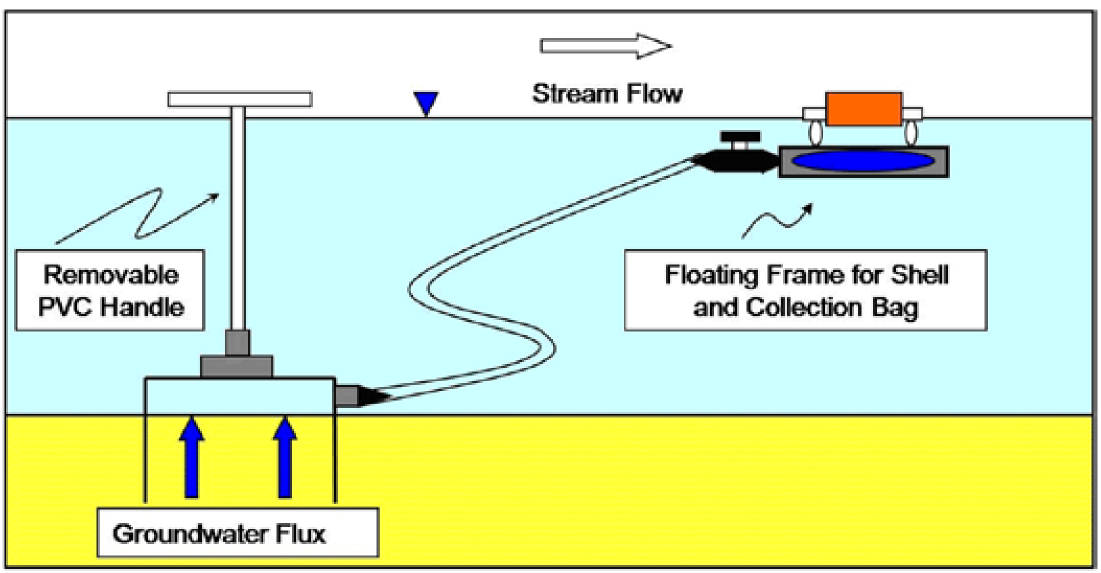

Figure 3. Cross sectional view of seepage meter that was used in water over 0.5 meters.

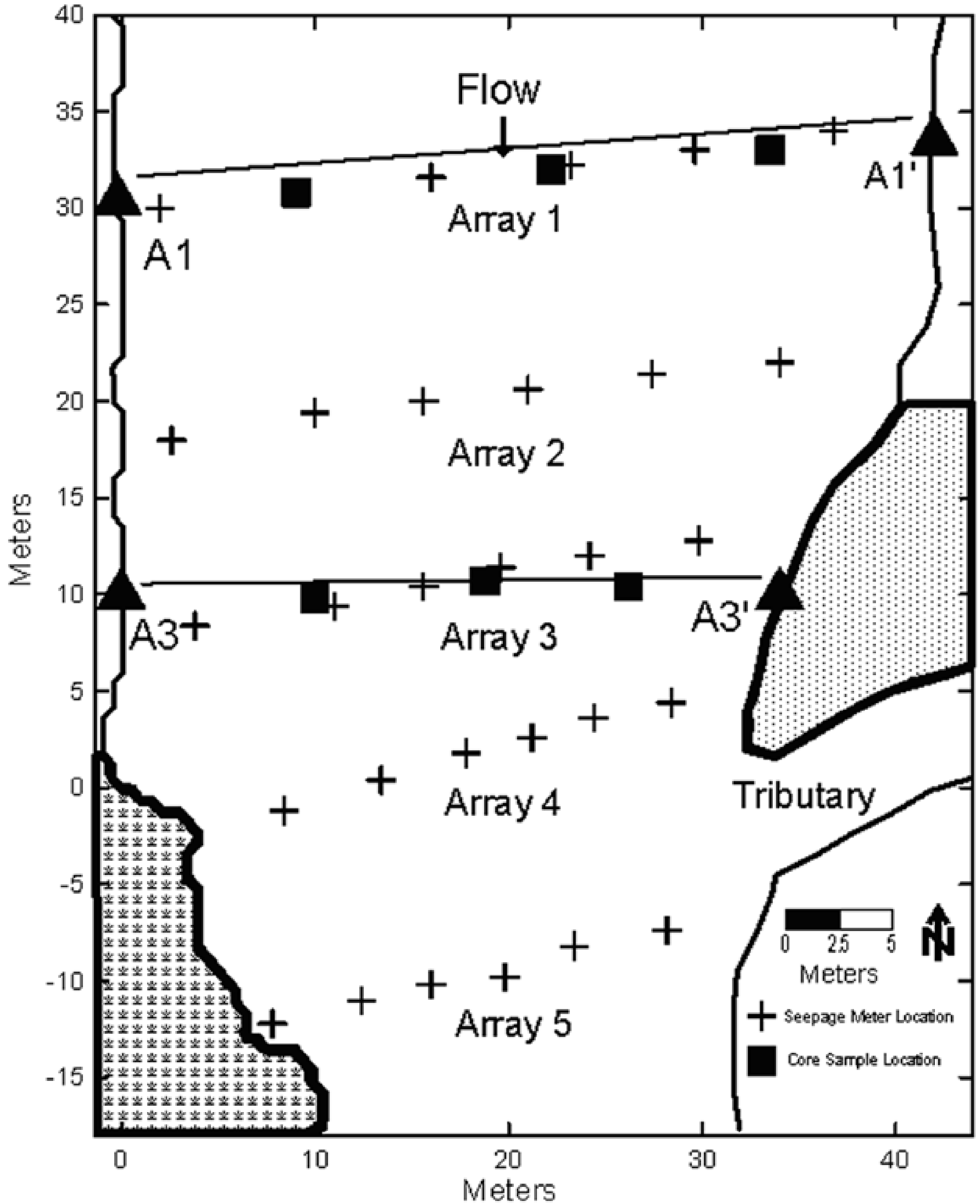

Figure 4. Base map of study area showing seepage meter locations (crosses) and core sample locations (squares).

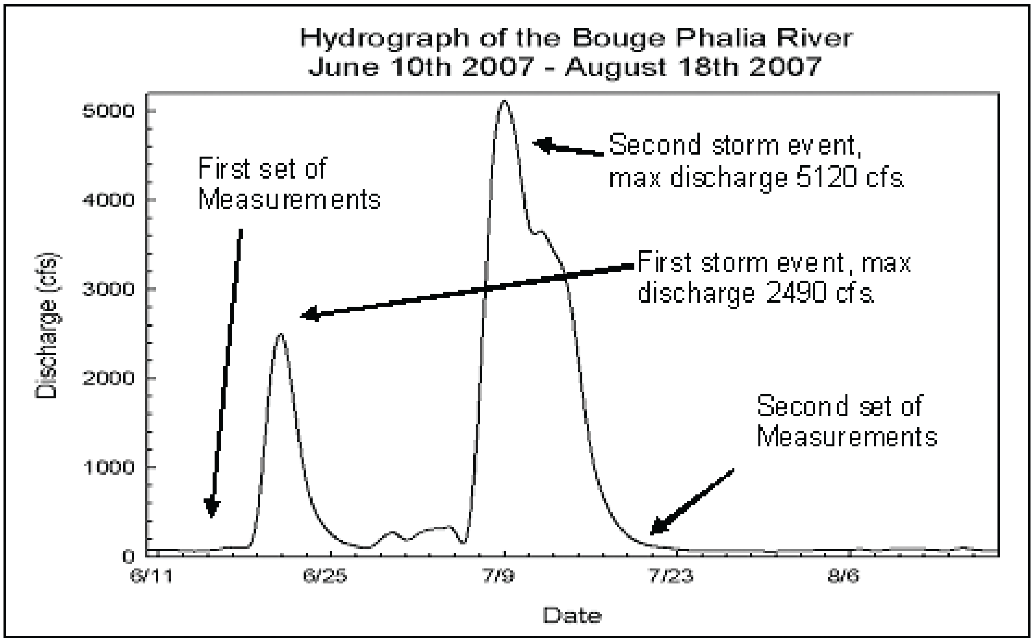

Figure 5. Hydrograph of the Bogue Phalia River during the field experiment. Data was taken from USGS Bogue Phalia #07288650 gauging station.

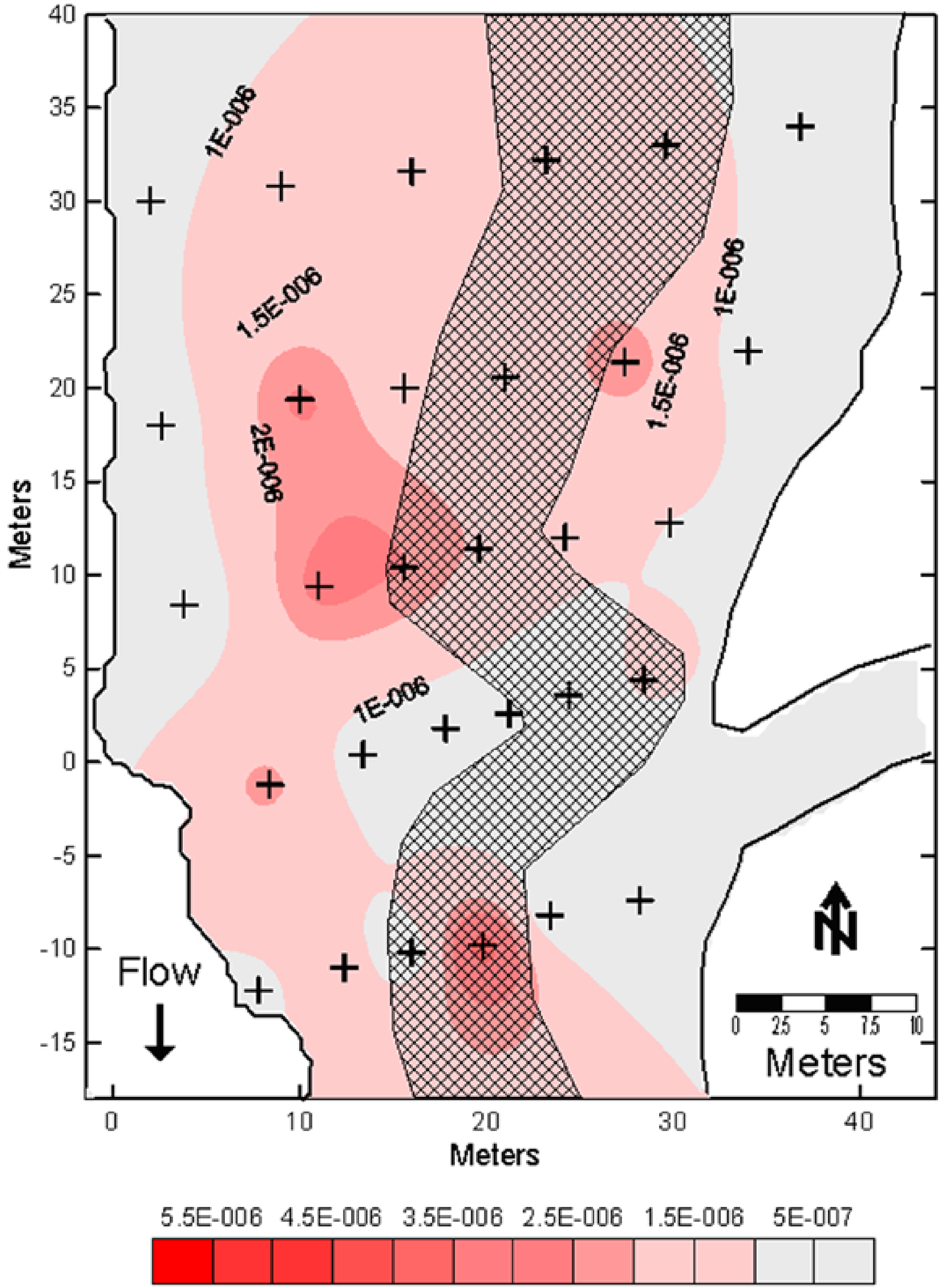

Figure 6. Map of vertical groundwater flux before the storm events at the Mark Rd Wading Station on the Bogue Phalia River.

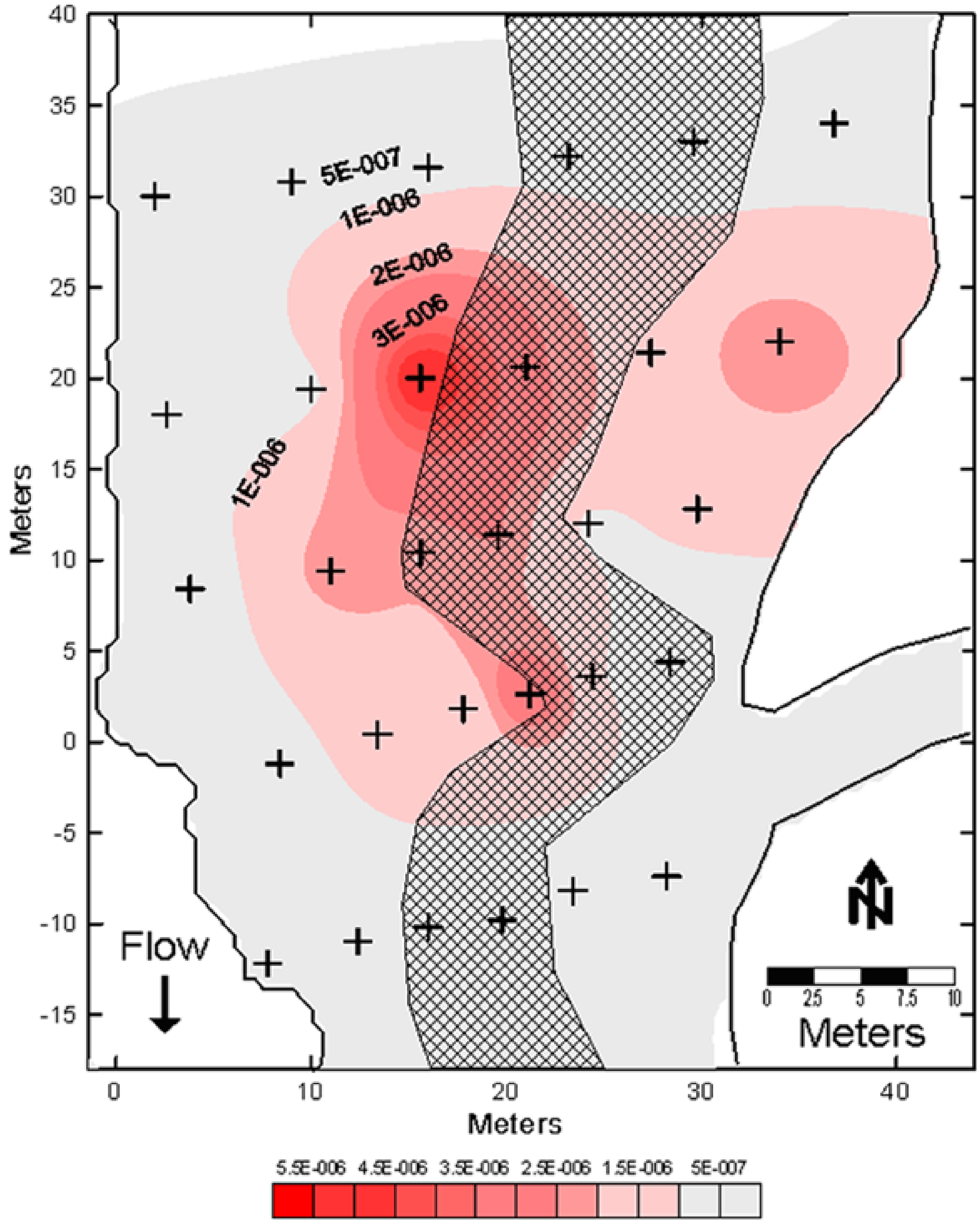

Figure 7. Map of vertical groundwater flux after the storm events at the Mark Rd Wading Station on the Bogue Phalia River.

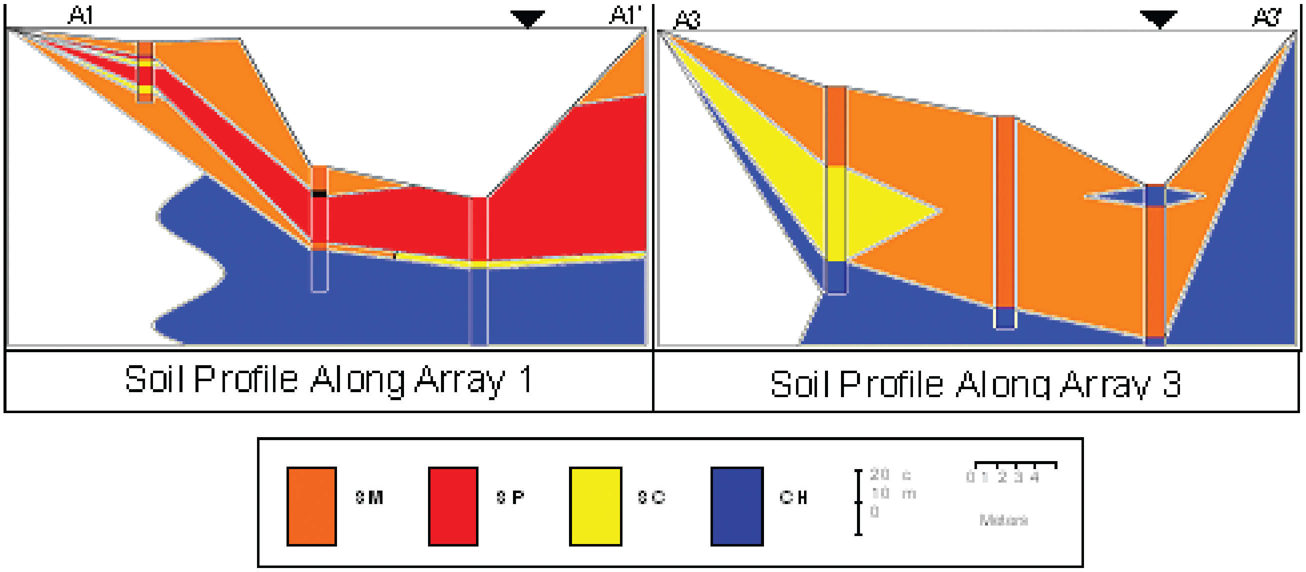

Figure 8. Cross-sectional view of soil distribution along specified arrays in the Bogue Phalia River at the Mark Rd Wading Station.