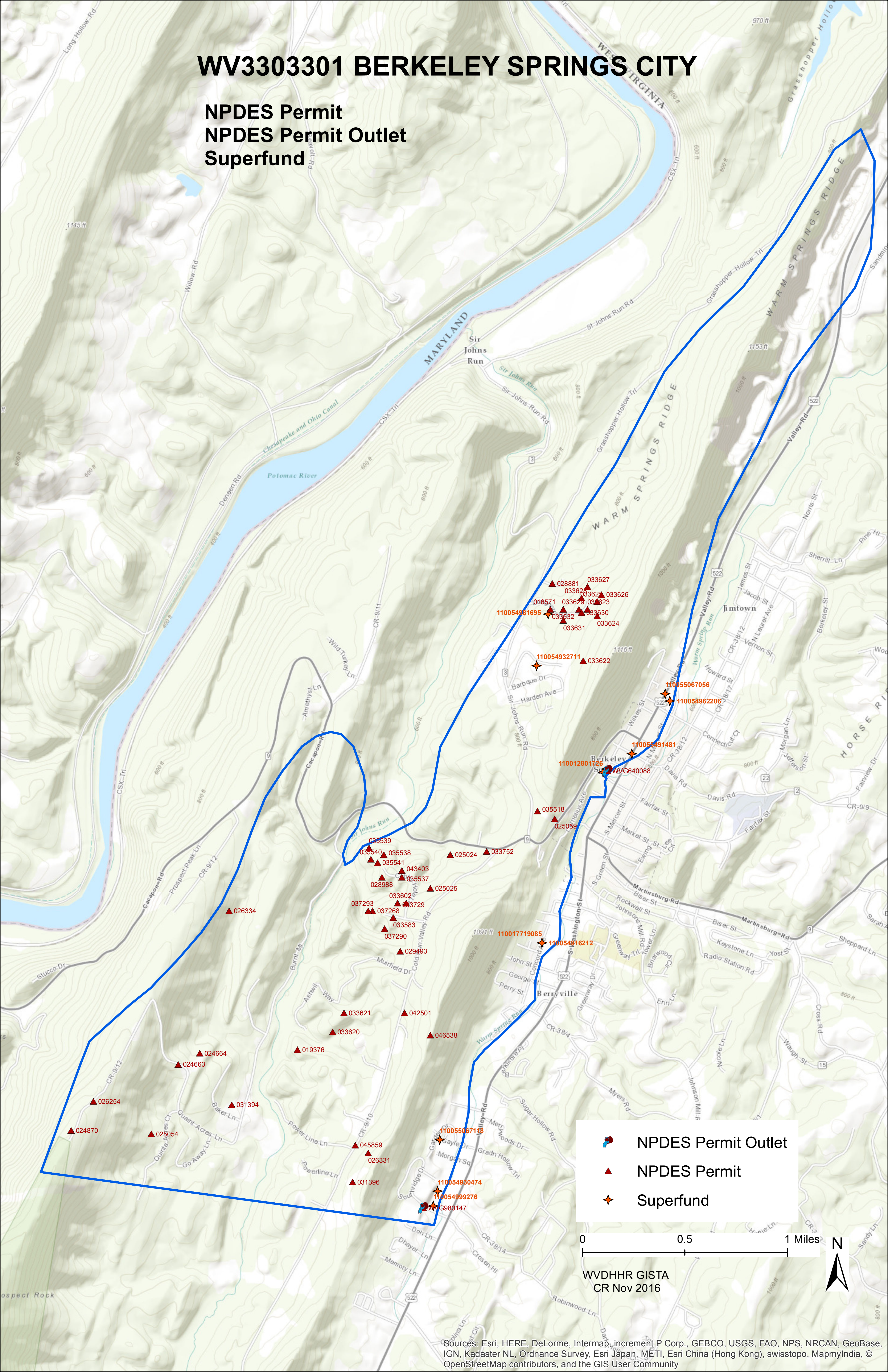
LUST SITES

| OBJECTID * | WVID__ | Leak__ | Facility_Name | Address | Project_Manager | Confirmed_Release | Cleanup_Initiated | Cleanup_Complete | Latitude_DD | Longitude_DD |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3304159 | 05-041 | BERKELEY SPRINGS STATION | 490 N WASHINGTON ST, | Moore, Sheena | 6/28/2005 | 6/28/2005 | 10/19/2005 | 39.63333 | -78.223611 |

| OBJECTID * | proj name | issue date | exp_date | project desc. | lat deg | lat min | lat sec | lon deg | lon deg | lon sec | proj status | owner name | contaminant | type inst_ | acres |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CSX - Berkeley Springs (VRP 07697) | 5/17/2006 | 9/26/2012 | VRP Project #07697 CSXT Former Wood Yard, Berkeley Springs, M | 39 | 37 | 54 | 78 | 13 | 26 | C | CSX Transportation, inc. | Railroad Depot | Land Use Covenant | 2.14 |
| 2 | Vernon Close Property (VRP 07650) | 4/24/2006 | NA | VRP Project #07650 Former Sunoco Facility (Duns 0000-0036) 3 | 39 | 37 | 47 | 78 | 13 | 38 | O | NA | Petroleum | NA | 0.3 |

# WV3303301 BERKELEY SPRINGS CITY

**NPDES Permit**
**NPDES Permit Outlet**
**Superfund**



WVDHHR GISTA
CR Nov 2016

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

| OBJECTID * | permit_id | fac_name | issuedate | expiredate | sub_desc | t_c_desc | latitude | longitude | resp_name | resp_id | avg_flow_q | rstream |
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| 1 | 33626 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63717 | -78.229066 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 2 | 35541 | NA | 10/29/2007 | NA | Septic Seal Permit | New | 39.62247 | -78.24485 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 3 | 28881 | NA | 1/17/2006 | NA | Septic Seal Permit | New | 39.63757 | -78.232466 | FORD, BOB & JEAN | 494477068 | -1 | N/A |
| 4 | 33620 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.61337 | -78.248016 | COLONIAL VILLAGE | 494482458 | -1 | N/A |
| 5 | 31396 | NA | 9/11/2006 | NA | Septic Seal Permit | New | 39.60504 | -78.246583 | SWINK, KENNETH L | 494479911 | -1 | N/A |
| 6 | 25025 | NA | 3/1/2005 | NA | Septic Seal Permit | New | 39.62105 | -78.241066 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 7 | 37268 | NA | 4/28/2008 | NA | Septic Seal Permit | New | 39.6199 | -78.245166 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 8 | 35537 | NA | 10/29/2007 | NA | Septic Seal Permit | New | 39.62163 | -78.243133 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 9 | 42501 | NA | 5/24/2010 | NA | Septic Seal Permit | New | 39.61425 | -78.2429 | STOTLER, MARSHALL TODD | 494495599 | -1 | N/A |
| 10 | 37293 | NA | 4/28/2008 | NA | Septic Seal Permit | New | 39.61993 | -78.245516 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 11 | 19376 | NA | 12/31/2003 | NA | Septic Seal Permit | New | 39.61228 | -78.250519 | LEVIN, MARC B | 494464888 | -1 | N/A |
| 12 | 24664 | NA | 2/14/2005 | NA | Septic Seal Permit | New | 39.61215 | -78.257451 | PITTMAN, ADRIAN | 494470620 | -1 | N/A |
| 13 | 28988 | NA | 1/17/2006 | NA | Septic Seal Permit | New | 39.62165 | -78.244583 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 14 | 25059 | NA | 3/1/2005 | NA | Septic Seal Permit | New | 39.62477 | -78.232283 | FARRIS, ROBERT | 494471735 | -1 | N/A |
| 15 | 24870 | NA | 2/24/2005 | NA | Septic Seal Permit | New | 39.60788 | -78.266528 | EDMONSTON, KURT & BONNIE | 494471610 | -1 | N/A |

| OBJECTID * | permit_id | fac_name | issuedate | expiredate | sub_desc | t_c_desc | latitude | longitude | resp_name | resp_id | avg_flow_q | rstream |
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| 16 | 45859 | NA | 12/15/2011 | NA | Septic Seal Permit | New | 39.60697 | -78.246416 | VOGT, TIM | 494501862 | -1 | N/A |
| 17 | 33621 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.61418 | -78.247183 | COLONIAL VILLAGE | 494482458 | -1 | N/A |
| 18 | 46538 | NA | 5/29/2012 | NA | Septic Seal Permit | New | 39.61297 | -78.24115 | BERNHARD, RAYMOND S | 494503371 | -1 | N/A |
| 19 | 33583 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.61943 | -78.243783 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 20 | 26334 | NA | 6/27/2005 | NA | Septic Seal Permit | New | 39.61978 | -78.255416 | HILL, JUDDIE THOMAS III | 494474025 | -1 | N/A |
| 21 | 33629 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63625 | -78.23065 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 22 | 29493 | NA | 3/6/2006 | NA | Septic Seal Permit | New | 39.61762 | -78.243233 | HOBDAY, JOHN | 494477606 | -1 | N/A |
| 23 | 33625 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63673 | -78.2294 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 24 | 33729 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.62022 | -78.2435 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 25 | 33602 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.62018 | -78.2428 | COBLE, TIM | 494482440 | -1 | N/A |
| 26 | 33627 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.6374 | -78.230066 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 27 | 33628 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63675 | -78.230433 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 28 | 31394 | NA | 9/11/2006 | NA | Septic Seal Permit | New | 39.60933 | -78.25515 | BAKER, PATRICIA &ROBERT | 494479910 | -1 | N/A |
| 29 | 16571 | NA | 5/13/2003 | NA | Septic Seal Permit | New | 39.63615 | -78.232614 | HOFFMAN, DARRELL & CHANTEL | 494461760 | -1 | N/A |

| OBJECTID * | permit_id | fac_name | issuedate | expiredate | sub_desc | t_c_desc | latitude | longitude | resp_name | resp_id | avg_flow_q | rstream |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | WVG640088 | Town of Bath | 9/26/2002 | 7/18/2018 | Water Treatment Plant (GP) | Renewed | 39.62751 | -78.228627 | BATH, TOWN OF | 355811 | 0.01 | Storm Drain/WARM SPRINGS RN/POTOMAC RV |
| 31 | 35539 | NA | 10/29/2007 | NA | Septic Seal Permit | New | 39.62315 | -78.2454 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 32 | 35540 | NA | 10/29/2007 | NA | Septic Seal Permit | New | 39.62257 | -78.245383 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 33 | 26331 | NA | 6/27/2005 | NA | Septic Seal Permit | New | 39.60657 | -78.245566 | STOTLER, SHANNON & MELANIE | 494474022 | -1 | N/A |
| 34 | 33624 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.6359 | -78.229316 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 35 | 26254 | NA | 6/27/2005 | NA | Septic Seal Permit | New | 39.60942 | -78.264916 | NEWCOMER, THOMAS & ESTHER | 494473992 | -1 | N/A |
| 36 | 33631 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63567 | -78.231683 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 37 | 37290 | NA | 4/28/2008 | NA | Septic Seal Permit | New | 39.61892 | -78.2443 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 38 | 25054 | NA | 3/1/2005 | NA | Septic Seal Permit | New | 39.60768 | -78.26085 | COHEN, DAVID P | 494471733 | -1 | N/A |
| 39 | 33630 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63613 | -78.230416 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 40 | WVG980147 | Morgan Cnty HQ | 2/19/2009 | 10/10/2016 | WV DOH+MUN | Renewed | 39.60361 | -78.241666 | WV DEPARTMENT OF TRANSPORTATION | 310668 | 0 | Warm Springs Rn/Potomac Rv |
| 41 | 35518 | NA | 10/29/2007 | NA | Septic Seal Permit | New | 39.62528 | -78.2335 | ANDREWS, LUCAS | 494485231 | -1 | N/A |

| OBJECTID * | permit_id | fac_name | issuedate | expiredate | sub_desc | t_c_desc | latitude | longitude | resp_name | resp_id | avg_flow_q | rstream |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 33632 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63625 | -78.231666 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 43 | 35538 | NA | 10/29/2007 | NA | Septic Seal Permit | New | 39.62295 | -78.244433 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |
| 44 | 24663 | NA | 2/14/2005 | NA | Septic Seal Permit | New | 39.61148 | -78.25894 | PITTMAN, ADRIAN | 494470620 | -1 | N/A |
| 45 | 33623 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63617 | -78.22995 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 46 | 43403 | NA | 9/23/2010 | NA | Septic Seal Permit | New | 39.622 | -78.243166 | KOONTZ, RON | 494496924 | -1 | N/A |
| 47 | 33622 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.63348 | -78.230333 | BRENT, GEORGE | 494480018 | -1 | N/A |
| 48 | 33752 | NA | 4/13/2007 | NA | Septic Seal Permit | New | 39.62313 | -78.237116 | PITTMAN, CAROL | 494482525 | -1 | N/A |
| 49 | 25024 | NA | 3/1/2005 | NA | Septic Seal Permit | New | 39.62287 | -78.239733 | BERKELEY PARTNERSHIP | 494471721 | -1 | N/A |

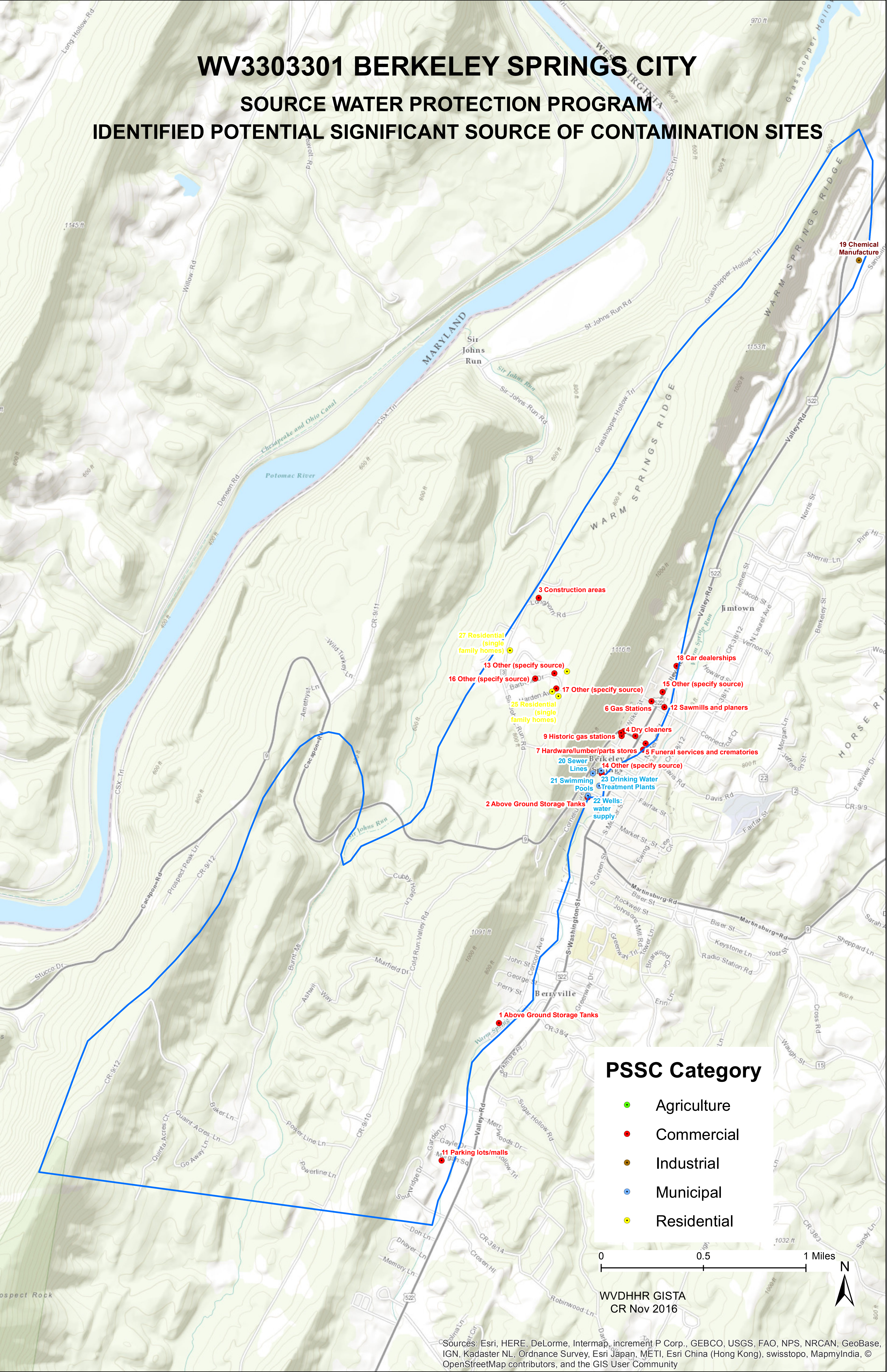
| OBJECTID * | permit_id | fac_name | issuedate | expiredate | sub_desc | t_c_desc | perm_type | iut_desc | latitude | longitude | rp_name | rp_id | avg_flow_q | rstream | rs_code | cnty_code |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | WVG980147 | Morgan Cnty HQ | 2/19/2009 | 10/10/2016 | WV DOH+MUN | Renewed | Industrial | Outlet | 39.60361 | -78.241666 | WV DOT | 310668 | 0 | Warm Spring Rn/Potomac Rv | P-10 | Morgan |
| 2 | WVG640088 | Town of Bath | 9/26/2002 | 7/18/2018 | Water Treatment Plant (GP) | Renewed | Industrial | Outlet | 39.62751 | -78.228627 | BATH, TOWN OF | 355811 | 0.01 | Storm Drain/WARM SPRINGS RN/POTOMAC RV | P-10 | Morgan |

SUPERFUND_RCRA FACILITIES

| OBJECTID _1 * | OBJECTID | PRIMARY_NA | LOCATION_A | Y | X |
|---|---|---|---|---|---|
| 1 | 10150 | BERKELEY SPRINGS HIGH | 149 CONCORD AVE. | 39.61822 | -78.23293 |
| 2 | 26490 | MORGAN CNTY HQ | US 522 | 39.62852 | -78.22658 |
| 3 | 23955 | RANKIN PHYSICAL THERAPY | US ROUTE 522 | 39.60389 | -78.240611 |
| 4 | 19303 | ROBERT L. FORD | WV SEC RT 3 | 39.63331 | -78.233306 |
| 5 | 25873 | RITE AID #2289 | 8 GAYLE DR | 39.6075 | -78.240155 |
| 6 | 25867 | WARM SPRINGS GARAGE | 1132 SOUTH VALLEY ROAD | 39.63178 | -78.224229 |
| 7 | 19212 | SOUTHRIDGE PLANNED UNIT DEVELO | US RT 522 | 39.60469 | -78.240306 |
| 8 | 22898 | ANCORA ESTATES | UNKNOWN | 39.63611 | -78.2325 |
| 9 | 19115 | BERKELEY SPRINGS HGH SCHOOL | 149 CONCORD AVE | 39.61822 | -78.23293 |
| 10 | 9156 | TOWN OF BATH | 103 WILKES STREET | 39.6275 | -78.228611 |
| 11 | 21537 | FORMER WOOD YARD | UNKNOWN | 39.63139 | -78.223889 |

# WV3303301 BERKELEY SPRINGS CITY

## SOURCE WATER PROTECTION PROGRAM
## IDENTIFIED POTENTIAL SIGNIFICANT SOURCE OF CONTAMINATION SITES



**PSSC Category**

- ● Agriculture
- ● Commercial
- ● Industrial
- ● Municipal
- ● Residential

WVDHHR GISTA
CR Nov 2016

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

| OBJECTID * | SITE_NAME | SITE DESCRIPTION | MAPCODE | Comments | OBJECTID | SOURCE_CAT | Associated_Chemicals | THREAT_TO_GW | THREAT_TO_SW |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Berkeley Springs school bus garage and parking lot | Above Ground Storage Tanks | C-1 | none | 23 | Commercial | PH, VOC | L | L |
| 2 | State park bath house | Above Ground Storage Tanks | C-1 | [redacted] | 23 | Commercial | PH, VOC | L | L |
| 3 | New Home Construction and Sediment Ponds. | Construction areas | C-10 | Site of R-5 thru R-7. | 32 | Commercial | M, T, PH, VOC, SOC, HM | M | H |
| 4 | Historic Dry Cleaners | Dry cleaners | C-12 | Now gift shop | 34 | Commercial | VOC, SOC | H | M |
| 5 | H.J. Funeral Home | Funeral services and crematories | C-15 | none | 37 | Commercial | M, MP, SOC, HM, VOC | M | L |
| 6 | Barker Auto Sales and gas station | Gas Stations | C-18 | none | 40 | Commercial | PH, M, VOC, SOC | H | M |
| 7 | Hunter Pro Hardware | Hardware/lumber/parts stores | C-21 | none | 42 | Commercial | VOV, SOC, HM, M | L | L |
| 8 | Historic gas station | Historic gas stations | C-23 | Now Town of Bath municipal building and Warm Springs PSD office | 44 | Commercial | PH, M, VOC | H | L |
| 9 | Historic gas station | Historic gas stations | C-23 | Now residence, groundwater remediation in progress | 44 | Commercial | PH, M, VOC | H | L |
| 10 | Whale of a Wash | Laundromats | C-27 | <Null> | 48 | Commercial | VOC, SOC | L | M |

| OBJECTID * | SITE_NAME | SITEDESCRIPTION | MAPCODE | Comments | OBJECTID | SOURCE_CAT | Associated_Chemicals | THREAT_TO_GW | THREAT_TO_SW |
|---|---|---|---|---|---|---|---|---|---|
| 11 | Morgan Square shopping center | Parking lots/malls | C-35 | Food Lion, Family Dollar, Whale of a Wash laundromat, etc. | 56 | Commercial | VOC, PH | L | M |
| 12 | Lumber stockpile - Closed | Sawmills and planers | C-46 | CSX Transportation Properties listed on No Trespassing sign | 67 | Commercial | PH, VOC, SOC | M | M |
| 13 | Triple B Café | Other | C-53 | Associated with performance venue (PCS 34). Possible septic system. | 74 | Commercial | <Null> | <Null> | <Null> |
| 14 | Antique Mall | Other | C-53 | Former car dealer | 74 | Commercial | <Null> | <Null> | <Null> |
| 15 | fire station - Closed | Other | C-53 | Currently a commercial building | 74 | Commercial | <Null> | <Null> | <Null> |
| 16 | Triple B Arena | Other | C-53 | Live music performance venue. Possible septic system. | 74 | Commercial | <Null> | <Null> | <Null> |
| 17 | Bob's Big Beef food distributor | Other | C-53 | Possible septic systems | 74 | Commercial | <Null> | <Null> | <Null> |
| 18 | Affordable Auto Sales and Service | Car dealerships | C-7 | 3 service bays | 29 | Commercial | PH, VOC | H | L |
| 19 | U.S. Silica plant | Chemical Manufacture | I-5 | Raw materials, finished material, processing facilities, and office campus | 86 | Industrial | PH, R, M, VOC, SOC | H | H |
| 20 | site of sewer line bust | Sewer Lines * | M-23 | past sewer line bust, repaired | 149 | Municipal | M, VOC, MP, TO | H | L |
| 21 | State park swimming pool | Swimming Pools | M-26 | none | 152 | Municipal | Chlorine | <Null> | <Null> |

| OBJECTID * | SITE_NAME | SITE DESCRIPTION | MAPCODE | Comments | OBJECTID | SOURCE_CAT | Associated_Chemicals | THREAT_TO_GW | THREAT_TO_SW |
|---|---|---|---|---|---|---|---|---|---|
| 22 | State park spring that supplies bathhouse | Wells: water supply | M-31 | none | 157 | Municipal | VOC, SOC | L | L |
| 23 | Berkeley Springs Drinking Water Treatment Plant | Drinking Water Treatment Plants | M-5 | Associated with R-15. | 131 | Municipal | D | L | L |
| 24 | Residential Area | Residential (single family homes) | R-4 | Possible septic systems | 166 | Residential | VOC, SOC, NN | H | H |
| 25 | Residential Area | Residential (single family homes) | R-4 | Possible septic systems | 166 | Residential | VOC, SOC, NN | H | H |
| 26 | Residential area with houses and trailers | Residential (single family homes) | R-4 | Possible septic systems | 166 | Residential | VOC, SOC, NN | H | H |
| 27 | Residential Area | Residential (single family homes) | R-4 | Possible septic systems | 166 | Residential | VOC, SOC, NN | H | H |

# APPENDIX B. EARLY WARNING MONITORING SYSTEM INFORMATION

## Proposed Early Warning Monitoring System Worksheet – Surface Water Source

| |
|---|
| **Describe the type of early warning detection equipment that could be installed, including the design.** |
| The early warning detection equipment that could be installed includes a level controller, display module, back panel, level & trough (see cost estimate by Hach Company in **Appendix E**) along with conductivity, oil-in-water, ORP, and pH sensors. |
| **Where would the equipment be located?** |
| Early warning monitoring systems would be located in the Berkeley Springs State Park spring channel approximately 25 feet upstream of where the raw water enters the raw water tank. |
| **What would the maintenance plan for the monitoring equipment entail?** |
| The proposed maintenance plan for the monitoring equipment shall consist of annual cleaning and/or exchanging of the probe(s) for the controller. Periodic calibration of the unit may also be required. |
| **Describe the proposed sampling plan at the monitoring site.** |
| Sampling of water quality data occurs every fifteen minutes allowing near real time monitoring within the water treatment plant. |
| **Describe the proposed procedures for data management and analysis.** |
| Data management for the early warning monitoring system consists of data points (up to 500 points or approximately six months per probe) being recorded in the "History" of the controller data collector. To access the "History", the probe has to be plugged into the controller. Data is able to be removed via USB or through a local SCADA system. |

*Literature related to the development and design of early warning systems is provided in the following pages courtesy of the American Water Works Association.*

BY RICHARD W. GULLICK, LEAH J. GAFFNEY, CHRISTOPHER S. CROCKETT, JERRY SCHULTE, AND ANDREW J. GAVIN

# Developing regional early warning systems

## FOR US SOURCE WATERS

REGIONAL EARLY WARNING SYSTEMS HELP IMPROVE MONITORING CAPABILITIES, FACILITATE COMMUNICATION AMONG UTILITIES, AND REDUCE RISKS TO PUBLIC HEALTH.

Early warning systems (EWSs) are used by water utilities to detect sudden changes in source water quality and are intended to provide information necessary to implement appropriate responses such as closing intakes or changing treatment methods. Rivers with several intakes over some distance are good candidates for multiple monitoring stations and coordinated data management and communication systems. In the United States, experience with such regional EWSs has largely been limited to the Ohio River and Lower Mississippi River. That situation has changed, however, with the recent development (or impending development) of regional systems on several other US rivers, including the Upper Mississippi, Schuylkill, Delaware, Allegheny, Monongahela, and Susquehanna. This article discusses the characteristics and ongoing development of these systems and the lessons learned through that process. These lessons may be applied to establish new regional EWSs on other rivers in the United States and elsewhere.

## EWS OPERATIONS HAVE COMMON FUNCTIONS AND CHARACTERISTICS

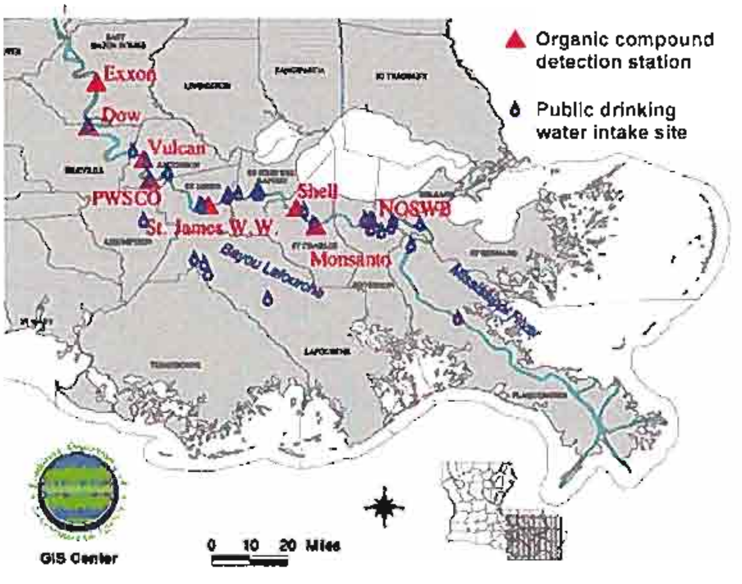
**Why EWSs are needed.** Most raw drinking water sources are susceptible to disruptions in quality as a result of accidental, intentional, or natural contamination. To protect consumers from potentially harmful contaminants, avoid treatment process upsets, and ensure compliance with environmental regulations, utilities must respond rapidly to spills and other sudden pollution events and make appropriate adjustments in drinking water treatment and operations. The timely information provided by an EWS can help guide utility response decisions and ensure that such decisions reflect actual data and circumstances. EWSs are used mostly on riverine systems where water quality can change rapidly (as a result of a barge spill near an intake, for example); the systems are used less frequently for impoundments and rarely for groundwater.

**Systems take various forms, serve several purposes.** EWSs comprise a combination of frequent or continuous monitoring, other detection mechanisms, institutional arrangements, analysis tools, and response protocols. Certain components are common to all capable EWSs and include the following:

**FIGURE 1 ORSANCO Organics Detection System stations on the Ohio River**

*ORSANCO—Ohio River Valley Water Sanitation Commission*

**FIGURE 2 Lower Mississippi River Early Warning Organic Compound Detection System**



*Source: Louisiana Department of Environmental Quality*

- *Detection:* a monitoring mechanism to detect pollution events and/or a public or self-reporting program.
- *Characterization:* a means to confirm and more completely characterize the event.
- *Communication:* the dissemination of data and other information to utility personnel and other decision-makers and response actions to the public and other stakeholders.
- *Response:* actions taken to minimize the potential effect of the contamination event. Responses could include source containment and/or cleanup, closure of water intakes and use of alternate sources or storage, and treatment process modifications.

Early warning monitoring can be used to detect rapid deterioration in water quality resulting from accidental or intentional discharges of toxic and hazardous chemicals near an intake. Such events as large-scale boat spills, pipeline breaks, industrial accidents, and terrorist attacks may be low in probability but can have significant consequences for water supplies. EWSs are also useful for monitoring during extreme natural events (such as heavy rains and flooding and algal blooms) and somewhat predictable events (such as seasonal runoff of herbicides).

Furthermore, EWSs can serve as a pollution prevention tool by tracking spill events and garnering information (to warrant followup activities and actions by agencies or prevention activities at similar sites), detecting unauthorized waste discharges, and serving as a sentinel of river water quality. In this last capacity, EWSs may tend to increase the number of spills reported but decrease the total number of spills, perhaps because of greater diligence on the part of potential dischargers.

**EWS scope depends on site-specific characteristics.** Onsite early warning monitoring may be conducted by a single water supplier (e.g., a single instrument at an intake). However, source waters used by multiple water utilities (e.g., a large river) offer opportunities for cooperation and pooling of resources for development of integrated regional EWSs, including multiple monitoring stations, centralized data management and assessment, and coordinated information communication systems. This article uses the term "regional EWS" to refer to a system with multiple users and/or monitoring stations.

Most regional EWSs are developed in a phased approach that incorporates additional monitoring capability over time. Monitoring techniques range from relatively simple online measurements (e.g., pH, turbidity) to video surveillance to advanced analytical instrumentation to the use of living organisms as bioalarms. Gullick and colleagues (2003) discuss EWS design for water utilities and the types of monitoring methods available; other references provide additional detail (Grayman et al, 2001; Gullick, 2001; Foran & Brosnan, 2000; ILSI, 1999). The sidebar on page 72 summarizes benefits provided by regional EWSs.

## EXISTING SYSTEMS PROVE VALUE OF EARLY WARNING MONITORING

On many rivers, there is no systemic monitoring for sudden water quality changes, and no coordinated communication or central reporting system currently exists. Around the world, relatively few regional EWSs exist using monitoring, modeling, and communications in an integrated system to provide warning of contaminants in the source water. Several prominent systems (most of them located in Europe or Asia) were described in detail by Grayman and coworkers (2001) and summarized by Gullick and colleagues (2003). Many of these systems were developed in response to a specific contamination incident.

These systems are diverse but share some characteristics. They may vary greatly in their degree of complexity and in terms of the frequency of analysis and degree of automation. The more sophisticated networks include a coordinated monitoring, modeling, communication, and response program for an extended stretch of river. In all cases, some form of institutional structure coordinates efforts and communicates information so that appropriate actions can be taken.

**Ohio River Organics Detection System.** The most established regional EWS in the United States is led by Ohio River Valley Water Sanitation Commission (ORSANCO) on the Ohio River. The Ohio River is a source of drinking water for about 3 million people, and more than 25 million people live in the watershed. The river is also heavily industrialized in sections, serves a significant amount of commercial barge traffic, and has hundreds of municipal, industrial, and combined sewer overflow discharges. The EWS includes 15 gas chromatograph stations at various locations to detect and monitor organic chemical spills (Figure 1). Data management and communications are coordinated by a single central office that communicates to utilities the nature of any detected spills or other changes in river water quality.

EWSs alert utilities of contaminants and allow them to initiate cleanups such as this one along the Schuylkill River following a chemical spill caused by a train derailment.

PHOTO: CHAD PINDAR, PHILADELPHIA (PA) WATER DEPT

Most of the monitoring stations are operated by water utilities at their intakes; others are run by industrial facilities. These organizations provide labor and space for sampling and analysis stations; analytical instruments are purchased and maintained by ORSANCO. All stations analyze at least one sample a day. Using a centralized data-analysis system and state-of-the-science contaminant transport models, ORSANCO is often able to provide utilities with specific estimates regarding the concentration–distance–time profile of chemicals spilled in the river. This information helps water utilities decide when to close their intakes and/or how to respond with modifications in treatment processes.

**Lower Mississippi River early warning organic compound detection system.** Another regional EWS is located in Louisiana on a 128 mi (206 km) stretch of the Lower Mississippi River from Baton Rouge to New Orleans (Figure 2). The system includes eight gas chromatographs (operated by three water utilities and five industries) monitoring for volatile organic chemicals. Although there is no central coordinating agency, the system is overseen by the Louisiana Department of Environmental Quality, which also provided financial support to purchase and maintain the gas chromatographs, accessories, and data-transmitting devices. The utility and industrial monitoring sites provide lab space and workers to analyze the samples. This system was inspired by the ORSANCO example and helps to protect the 1.5 million Louisiana residents who depend on the river for their drinking water supply (Grayman et al, 2001).

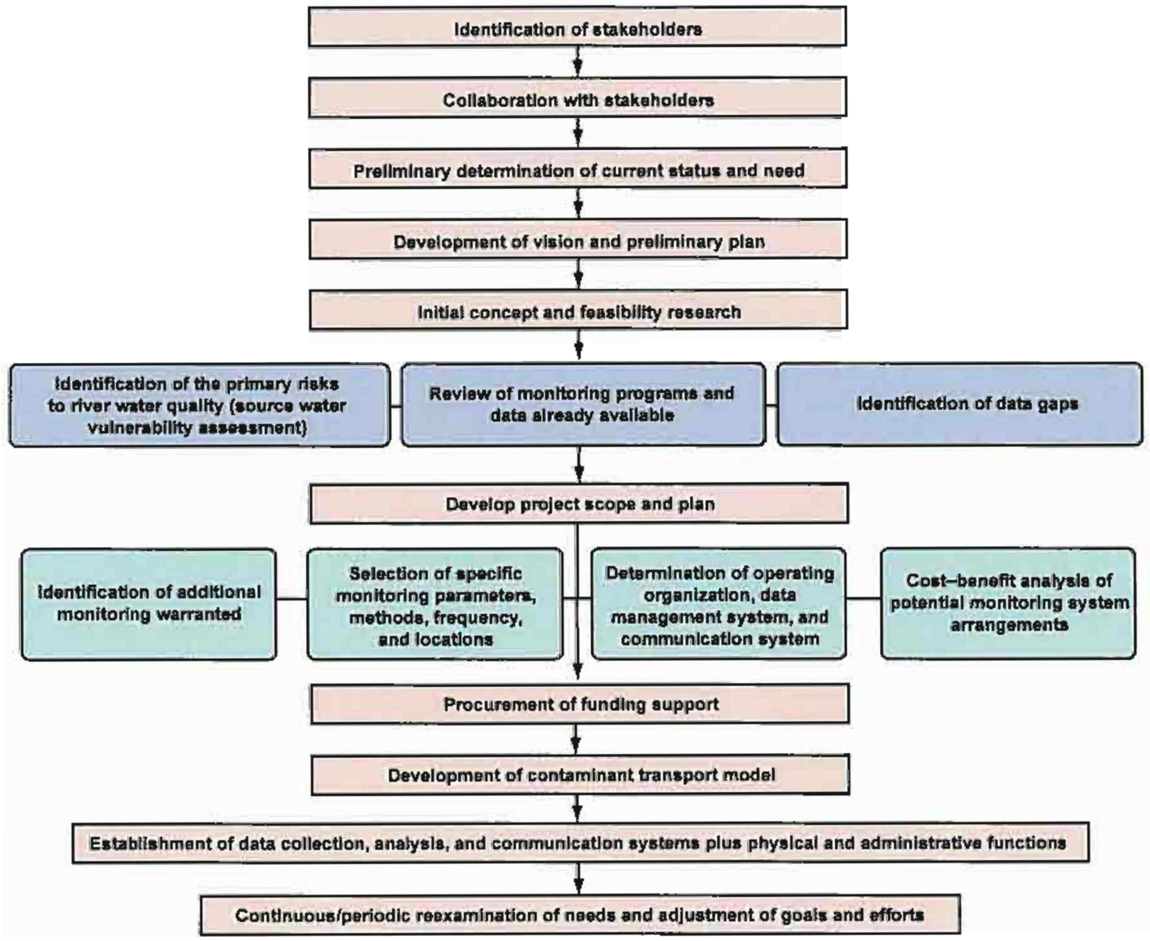
## EARLY WARNING MONITORING IS ON THE RISE IN THE UNITED STATES

Interest in regional EWSs has increased in recent years, with systems currently in development for the Upper Mississippi, Schuylkill, Delaware, Allegheny, Monongahela, and Susquehanna rivers (Gullick, 2003). These systems are being designed to answer system-specific needs, and they reflect their individual locations and participating entities. However, the regional EWSs also have some characteristics in common. To some degree, each EWS was modeled after parts of the ORSANCO system, and each aspires to achieve these shared goals:

- Provide prompt notification of significant watershed events to downstream users.
- Provide information and tools to aid water suppliers in making decisions.
- Develop a framework to share information about water quality.
- Improve communication among water suppliers about water quality events.
- Improve communication between water suppliers and emergency responders.

The primary processes involved in the development of a typical regional EWS are shown in Figure 3. The following sections describe the monitoring and communication systems being developed as of April 2004 for the Delaware Valley, Upper Mississippi River, Allegheny and Monongahela rivers, and Susquehanna River.

**FIGURE 3 Processes involved in the development of a typical regional early warning system**



**Delaware Valley (Schuylkill and Delaware rivers).** The Delaware River Basin (Figure 4) drains an area of 13,300 sq mi (34,447 km$^2$) in the states of New York, Pennsylvania, New Jersey, and Delaware. The Delaware River is the longest undammed river east of the Mississippi, stretching 330 mi (531 km) from its headwaters in New York state to the mouth of the Delaware Bay (PWD, 2002). The Schuylkill River is 130 mi (209 km) long and is the largest tributary to the Delaware River. Its basin drains an area of 1,900 sq mi (4,921 km$^2$) in Pennsylvania.

The Delaware and Schuylkill rivers serve as the source water for more than 3 million people in southeastern Pennsylvania and southwestern New Jersey. Although both rivers originate in rural areas, their confluence in the Delaware Estuary promoted the development of the urban, industrial, and shipping center that is the Philadelphia–Camden metropolitan area. Their location and upstream activities render the rivers highly vulnerable to water quality contamination events and ideal candidates for a source water EWS.

*Utility spearheaded EWS development.* The Philadelphia Water Department (PWD) operates the three drinking water treatment plants farthest downstream on the Delaware and Schuylkill rivers. The utility gained familiarity with both watersheds during development of the Source Water Assessment Program (PWD, 2002). While working with neighboring water suppliers, PWD identified the need and gathered support for the development of a watershedwide EWS. In the aftermath of Sept. 11, 2001, and after five years of campaigning, PWD received a one-year, $725,000 grant from the Pennsylvania Department of Environmental Protection (PADEP) to develop an EWS. Although the monetary resources were significant, the one-year time frame posed a significant challenge.

*PWD sought stakeholder input.* From the beginning, stakeholder involvement was an integral part of the EWS development. Even before the grant was awarded, PWD approached a select group of water utilities to gain their support, identify the overall goals of the EWS, and develop the basis for a proposal. After PADEP awarded the grant and

## POTENTIAL BENEFITS OF REGIONAL EARLY WARNING SYSTEMS

A regional early warning system shared and supported by a group of water providers offers numerous benefits.

- Improved monitoring can detect sudden changes in river water quality.
- Identification of spills/releases that are unknown to the dischargers may help them to prevent similar releases in the future.
- Communication of contamination events to water utilities is improved.
- Better information on contamination events allows for better response decisions.
- The overall risk to the public from spill events is reduced.
- Water providers share more kinds of information, and communication among utilities is increased.
- Monitoring efforts on the river are better coordinated.
- The system can serve as a monitoring sentinel, thus promoting greater diligence on the part of potential dischargers.
- Public confidence in potable water quality is improved.
- Additional information provided by the system can help in responding to the press during spill events.
- A central data warehouse may be beneficial to researchers studying the river.
- Source water protection of a large river is complex and may not be feasible. Time, energy, and money may be better spent on reliable early notification systems and installation of water treatment processes to deal with potential contamination events.

Adapted from Gullick et al, 2003

the project was formally under way, PWD approached a broader group of stakeholders through a series of meetings, site visits, and surveys. This group included representatives from 14 water utilities along the main stem of the Schuylkill and Delaware rivers, county emergency management agencies, and regulatory agencies (e.g., PADEP) the New Jersey Department of Environmental Protection, and the US Environmental Protection Agency (USEPA), as well as other organizations such as the US Geological Survey (USGS), the Delaware River Basin Commission, and the US Army Corps of Engineers (USACE). This diverse group brought a wide array of experiences, capabilities, priorities, and needs to the EWS development process. This in turn created both greater opportunities and significant challenges in meeting the varied expectations.

Input from the stakeholders helped to identify their needs and resources and enabled the design of an EWS that complemented existing emergency notification and response protocols. In addition, the stakeholder process identified the need for a system that could provide information and tools useful in the daily operation of a water treatment plant. This provision increases the overall value of the system and encourages users to become acquainted with the system as part of their routine operations.

***System developed quickly.*** The Delaware Valley EWS was designed to provide the infrastructure for a notification, communication, monitoring and data-management system that could expand and develop over time. The objectives during the first year of the project were to build a framework that would support emergency notifications, promote routine information-sharing, and demonstrate the potential for a watershedwide water quality EWS. The resulting EWS is a fully integrated computer-based system that includes three major components: a telephone-based notification system, a website and data-management system, and a water quality-monitoring network (Figure 5).

The telephone notification system is an off-the-shelf application that was customized for the Delaware Valley EWS. The telephony system accepts calls from emergency responders or water utility personnel, records event information provided via touch-tone responses to a standard question-and-answer process, and makes telephone and e-mail notifications. The telephony system is integrated with the EWS server and can forward event information to the EWS database and website.

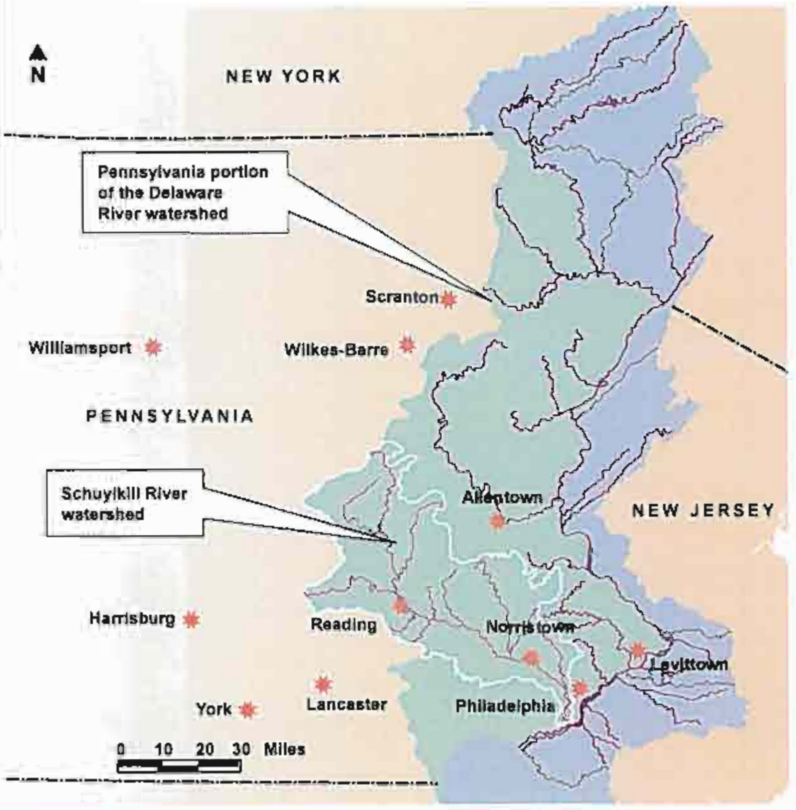
The computer server, which houses the website, data-management system, and telephony system, is the core of the Delaware Valley EWS and the central location for all EWS information. The data-management system stores and organizes information about contamination events, water quality, and plant operational characteristics in an accessible format. The result is a unique and powerful tool that sets this EWS apart from others currently in operation.

The Delaware Valley EWS website provides a dynamic and interactive user interface to the database, allowing users to access and share event and water quality information in a centralized and secure location. Various user interface formats are available, including forms for reporting and viewing the details of a water quality event (Figure 6), maps to identify the location of an event (Figure 7), graphs that show water quality data (Figure 8), and a time-of-travel estimator (Figure 9). The estimator uses real-time flow data from USGS gauging stations to provide plug-flow travel time estimates for each intake based on river conditions at the time of the event. To provide additional boundaries on this rough estimate, the historical highest flow and lowest flow on record at the gauging stations are used with a hydrodynamic water quality model to provide estimates of the earliest and latest times it would take for the spill to reach a downstream intake.

The water quality monitoring network compiles both near real-time and historic water quality data. The near real-time portion of the network uses simple and readily available technology to transmit data from remote monitors to the EWS server on a set time interval. Continuous monitors are located at select water treatment plant intakes and USGS gauging stations. Real-time monitoring was initially limited to simple water quality parameters such as turbidity and pH, but the network will be expanded in future years as monitoring technologies advance and additional monitoring needs are identified. In addition to the near real-time data, utilities will submit the results of their routine operational monitoring, creating a historical database that can be compared with real-time data.

***Automation was essential to system design.*** One of the great challenges in designing this system was meeting the requirement that it operate essentially unstaffed. This is a different approach from that taken by many existing systems, which use an organization to oversee the monitoring and notification process 24 hours a day, seven days a week. With the Delaware Valley EWS, once an event is reported via telephone or the Internet, the system automatically performs the time-of-travel estimations and notifies downstream users. System users then supplement the event description by reporting updates and additional information to the website. This inherent reliance on the users places the success of the Delaware Valley EWS firmly in their hands.

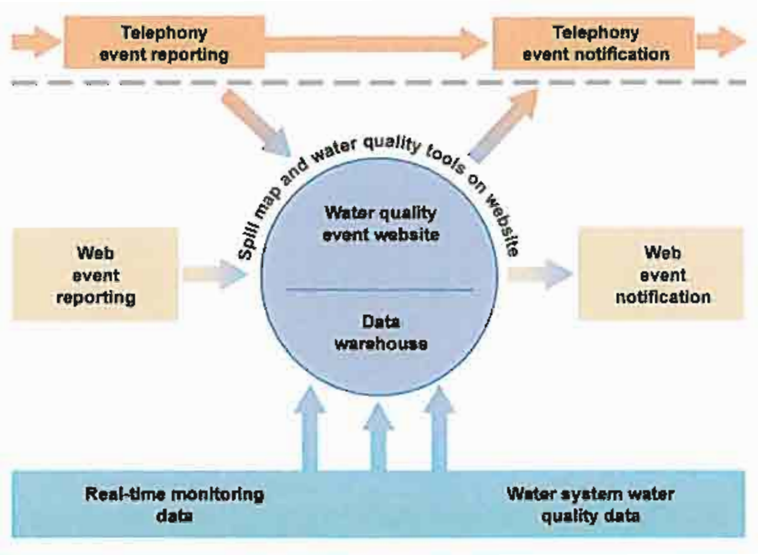
**FIGURE 4 Delaware River Basin**



***Steps were taken to ensure organizational sustainability.*** Maintaining stakeholder partnership will be crucial to the long-term success of the Delaware Valley system. A steering committee was formed to act as the EWS governing body and to promote sustainability by giving stakeholders a more active role in defining the future of the system to meet their needs. The steering committee will identify issues and make decisions to guide the system's future development and maintenance, as well as locate and allocate funding. The steering committee comprises the nine voting seats of participating utilities (Table 1). Government agencies and other organizations do not have voting seats but participate by serving in an advisory role. Steering committee meetings are open to all stakeholders.

***Implementation demonstrated system's value.*** During the first three months of EWS operation, seven water quality events of varying types and magnitudes were reported. Three events were associated with algal blooms or taste-and-odor events and their effects. One was related to high ammonia concentrations from road salt runoff affecting water treatment, and another was attributable to sewage main breaks spilling into the river. The final two events were related to spills—one a fuel spill of unknown origin and the other a tanker truck accident. The tanker truck accident in particular demonstrated the value of the Delaware Valley EWS. Initially the tanker truck was reported to have overturned on a bridge over the river just 3 mi (5 km) upstream of an intake, releasing approximately 100 gal (379 L) of diesel fuel into the river. During this event, the EWS was able to assist emergency response personnel and provide timely notification and pertinent data to downstream water sup-

**FIGURE 5 Delaware Valley early warning system schematic**



pliers so they could initiate their respective responses to the event with the best available information.

*As system uses multiply, support for the Delaware Valley EWS grows.* The response and enthusiasm for participation in the Delaware Valley EWS have been positive, and more industrial users, water suppliers, and organizations are participating in the system as word spreads and users are trained. For example, a county health department requested that the system be expanded to include its entire county. The growing support for the EWS is due primarily to the potential of the system's alternative uses that indirectly benefit the day-to-day activities of participants. Examples of indirect uses being explored include: health departments turning to the EWS for help with investigating disease clusters related to recreational waterborne outbreaks, food and beverage manufacturers obtaining advance warning of potential water quality changes that might affect processing, water suppliers obtaining official reports to justify additional chemical costs (e.g., carbon addition) during events, emergency responders using EWS data to assist in documenting accidents, and recreational events and users relying on the system for forecasts of water quality. As these potential multiple uses evolve, the usefulness and the long-term success and sustainability of the system increase.

**Upper Mississippi River.** The Upper Mississippi River refers to the approximately 1,300 mi (2,092 km) stretch of the Mississippi River from the headwaters to the confluence with the Ohio River at Cairo, Ill. (Figure 10). This definition excludes the Missouri River, the river's largest tributary. Other significant tributaries of the Upper Mississippi include the Illinois, Minnesota, St. Croix, Wisconsin, and Kaskaskia rivers (UMRBA et al, 2004).

A vital economic link for America's heartland, the Upper Mississippi River supports commercial navigation, water supply, recreation, wildlife, and waste-discharge assimilation. The river is a major transportation artery, and land use along its banks ranges from major metropolitan areas to rural farmland. A system of 29 locks and dams maintains a 9 ft (3 m) deep channel, allowing navigation as far upstream as Minneapolis, Minn. (UMRBA et al, 2004). The drainage area for the Upper Mississippi River is approximately 189,000 sq mi (489,510 km$^2$), primarily from the five states bordering the river (Minnesota, Wisconsin, Iowa, Illinois, and Missouri). The average flow of the river as it approaches Cairo is approximately 121 bgd (458 GL/d).

The Upper Mississippi River has 26 drinking water suppliers with a total of 29 intakes over an 874 mi (1,407 km) stretch from Minnesota to Missouri. Of these suppliers, 23 are community systems, and the remainder are industrial facilities (noncommunity systems). These 26 water suppliers combined provide approximately 360 mgd (1,363 ML/d) of potable water to almost 3 million people. There are three drinking water intakes between St. Cloud and the Twin Cities of Minneapolis and St. Paul in Minnesota. Then for a stretch of 370 mi (595 km) there are no drinking water intakes downstream until the Quad Cities (Davenport, Rock Island, Molina, and Bettendorf) of Illinois and Iowa.

*Regional organization assumes project leadership.* Initially the work to develop a regional EWS on the Upper Mississippi River was led by American Water, a privately owned water supplier with four intakes on the river (Gullick, 2001). With the support of Region 5 of the USEPA, the Upper Mississippi River Basin Association (UMRBA), an organization representing the five states bordering the river, eventually took over the lead for assessing the potential for a regional EWS. UMRBA then formed an official Upper Missouri River EWS scoping group to help explore design and operational issues. The group includes representatives of drinking water suppliers and state and federal response and drinking water programs.

*Key stakeholders contribute to EWS development.* Following American Water's first efforts to assess the potential for a regional EWS on the Upper Mississippi River, other entities have made important contributions to this collaborative effort. In addition to the water suppliers, UMRBA has been instrumental throughout the project. UMRBA coordinates the efforts of the Upper Mississippi River Hazardous Spills Coordination Group, composed of state and federal agencies that have various response-related roles on the river. Discussions were also held with many of the individual agency members of the spills group, including USEPA and USACE. Representatives from ORSANCO and a research project sponsored by the AWWA Research Foundation (Grayman et al, 2001) served as consultants and provided significant advice and input.

*Coalition of water suppliers formed.* Realizing that the support of the water suppliers on the river would be crucial to development of a regional EWS, American Water initiated steps early on to organize these providers into a coalition to better represent their collective interests. The first meeting of the Upper Mississippi River Water Suppliers Coalition was held in October 2001 in Davenport, Iowa. The primary goals of the coalition are to establish a formal communication network for the water suppliers on the river, develop a regional EWS, promote source water protection practices, provide educational opportunities for the membership and their consumers, develop working relationships with other river stakeholders, and serve as a resource clearinghouse for river water quality and related information.

Coalition members can include both public and privately owned water utilities as well as industries and other organizations that operate noncommunity water systems using the Upper Mississippi River as a source. State and federal agencies responsible for drinking water, river pollution, and spills response also participate in the coalition's meetings, although they are not official members of the coalition and have no voting powers.

A series of meetings and conference calls was held to initiate the project. More stakeholders have become involved at each step of the process and particularly at each of the meetings. One primary focus for the water suppliers was to encourage the spills group and the relevant state and federal agencies (public water supply and hazardous spill-response divisions) to support development of a monitoring network. On more than one occasion, the water suppliers coalition and the spills group have met jointly, providing opportunities to exchange experiences, perspectives, and concerns.

**FIGURE 6** **Sample Delaware Valley early warning system user interface screen for a hypothetical spill event—water quality event report form**

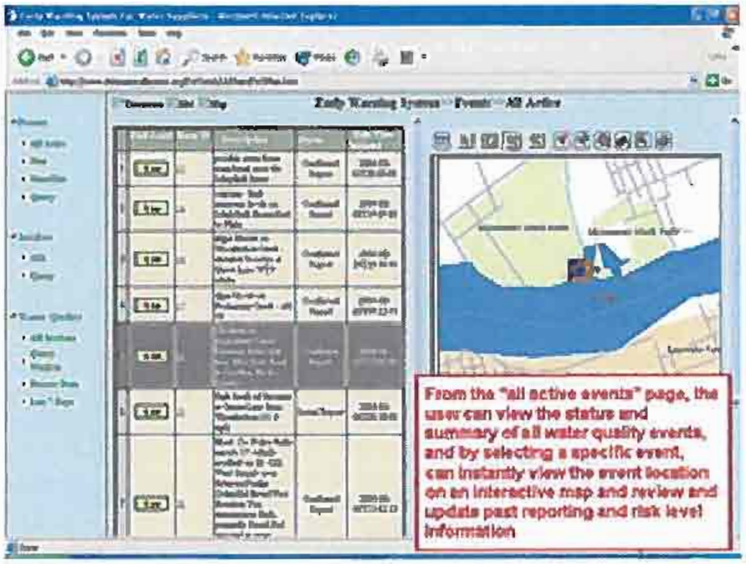
When a contamination event is entered online an immediate email notification is sent to all downstream users providing detailed event information together with a model estimating the time at which the contaminant will reach a given downstream drinking water intake.

*Existing monitoring programs identified.* One important early step in the process was to identify and describe the existing river water quality monitoring programs conducted by the water suppliers as well as federal, state, and local agencies to ascertain what information would be useful for early warning monitoring. This investigation showed that despite the existence of numerous water quality monitoring programs on the Upper Mississippi River, little monitoring was being performed that would be applicable to an EWS because of the types of parameters monitored (primarily oriented toward Clean Water Act compliance or measurement of ecological health), the relatively low frequency of monitoring (e.g., once every two weeks or monthly), and the location of most of the monitoring stations substantial distances away from the water supply intakes (Gullick, 2001).

A survey of the water suppliers was used to identify the type and frequency of source water monitoring already being performed, as well as the primary risks to river water quality. Oil and petroleum products, bacteria, algae, ammonia, and pesticides (herbicides and/or insecticides) were identified as the most common contaminants of the source water. According to the water suppliers, the leading sources of contaminants on the river were barge and boat spills, industrial spills, low flows, wastewater treatment plants, and runoff. Transportation accidents were viewed as by far the biggest threat.

Despite these risks to water quality, however, the same survey indicated that little monitoring was being performed to provide advance warning of many of these contaminants.

**FIGURE 7** **Delaware Valley early warning system user interface for a hypothetical spill event—all active events screen**



From the "all active events" page, the user can view the status and summary of all water quality events, and by selecting a specific event, can instantly view the event location on an interactive map and review and update past reporting and risk level information

Daily or frequent monitoring by intake operators was generally limited to basic physical and chemical parameters such as pH, turbidity, nutrients, and suspended solids. Turbidity and pH were the only two parameters that all of the survey respondents measured at least once a day, and only eight suppliers had continuous monitors for one or both of these parameters. Sampling frequencies for other parameters varied greatly and were typically low. In summary, the water quality data being collected were insufficient to support a regional EWS, and no central reporting system existed to track water quality data produced by the suppliers.

***Funding draws on a range of sources.*** Initial financial support came from American Water and UMRBA, primarily in terms of personnel to perform the first exploratory work. More recently, USEPA Region 5 has provided up to $75,000 through a cooperative agreement with UMRBA to support the scoping effort and acquire monitoring equipment for a pilot station; USEPA has also provided additional contractor assistance in designing the system. Additional support has come from in-kind contributions of time from various members of the scoping group and water suppliers coalition.

***Work proceeds on data collection, analysis, and dissemination system.*** Data-management and communication-system options are still being developed as part of the scoping effort. In April 2003, the scoping group surveyed members of the suppliers coalition concerning information dissemination and spill notification. Seventeen of the 23 organizations with intakes responded, generally expressing strong interest in a secure, web-based system that would notify them of contamination, provide ongoing information during an incident, and afford an opportunity to exchange information concerning routine operations. Most respondents indicated a willingness to share their own monitoring and testing results with other participants in the system, assuming a reasonable level of security could be ensured. This would allow the utilities to exchange data on parameters for which they test either routinely or seasonally but that may not be part of the EWS protocol; such parameters include bacteria, oxidant demand, and atrazine. The EWS scoping group is considering the results of this survey, as well as the experience of other EWSs, in identifying the key components of a data collection, analysis, and dissemination system. Particular attention will be paid to the potential to build off of one or more of the frameworks already in use or under development by the other regional EWSs discussed in this article.

***Pilot program launched for Upper Mississippi River EWS.*** The EWS scoping group is currently coordinating implementation of a pilot monitoring station that is slated to include a multiparameter probe[1] for pH, turbidity, chlorophyll, conductivity, dissolved oxygen, temperature, and oxidation–reduction potential, as well as a continuous online fluorescence detector[2] for oil and petroleum products. The multiparameter probe was deployed in October 2003, and the initial experience with this equipment has generally been positive. Efforts are ongoing to address site and operating requirements related to the fluorescence detector. The scoping group's intent is to operate the pilot station for a sufficient period to gain operating experience over different conditions (winter temperature and ice conditions in the region can be particularly severe), identify threshold values for the various parameters, and evaluate alternative data-transmission options. Initially, the pilot station is transmitting data via satellite to a USACE website.

The pilot monitoring station is located at one of the USACE lock and dam sites where a municipal water supply intake for the city of Rock Island, Ill., is located. This location allows the scoping group to pilot an interagency, cooperative approach to operation of an EWS station. Corps personnel have provided extensive technical support concerning equipment installation and data transmission while also assisting Rock Island city personnel in maintaining and calibrating the equipment. If this interagency approach for the pilot is successful, it may prove to be a model for the final design of a regional EWS for the Upper Mississippi River.

*Potential monitoring locations considered.* Facilities that may serve as monitoring locations for the Upper Mississippi EWS include the water treatment plants, existing USGS and state monitoring stations, USACE lock and dam locations, and industrial facilities such as power plants. Factors determining the selection of monitoring sites will include the locations of potential contamination sources in relation to the location of water supply intakes, the risk these sources pose, and the willingness of various entities to participate.

*Cost estimates vary.* One proposed network of nine monitoring locations was estimated to cost about $550,000–$600,000 in capital expenses, $40,000–$50,000 for system startup, and $280,000–$340,000 in annual operating costs (Gullick, 2001). This estimate included purchase of monitoring (multiparameter probe and fluorescence detector) and telemetry equipment, daily analysis of oxidant demand, seasonal daily immunoassay analyses for atrazine, sheds for housing equipment, operating costs for the data-management and communication systems, and other items. It also assumed in-kind support from the water suppliers with monitoring stations to perform analyses and report results. The EWS scoping group will develop a refined estimate that reflects experiences with the pilot station, recommended monitoring locations, desired information system features, and other factors.

*Project moves forward.* Bringing the EWS to fruition involves the following steps: (1) complete pilot program, (2) develop institutional structure (data-management center and communications system), (3) complete full-scale system design (including finalizing monitoring parameters, methods, locations, and frequency), (4) develop contaminant transport model, (5) obtain long-term funding, and (6) launch system setup and operation. Several of these efforts will take place concurrently.

**FIGURE 8** Example of Delaware Valley early warning system user interface screen—water quality data query results

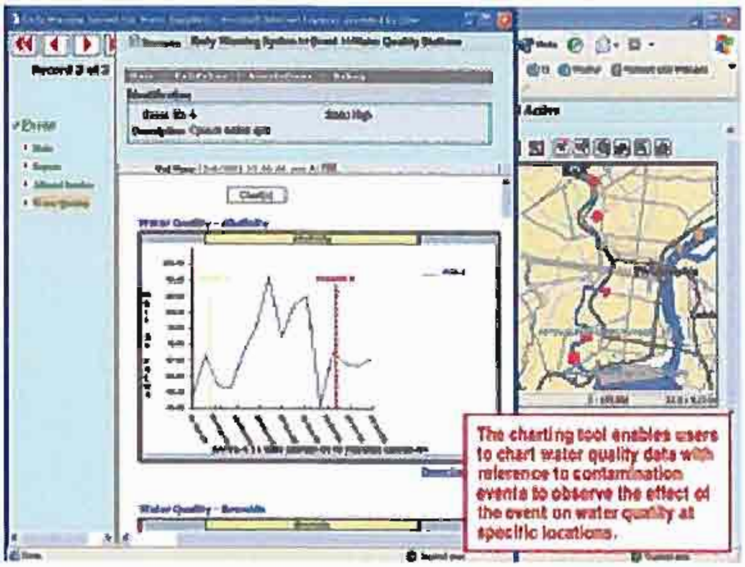
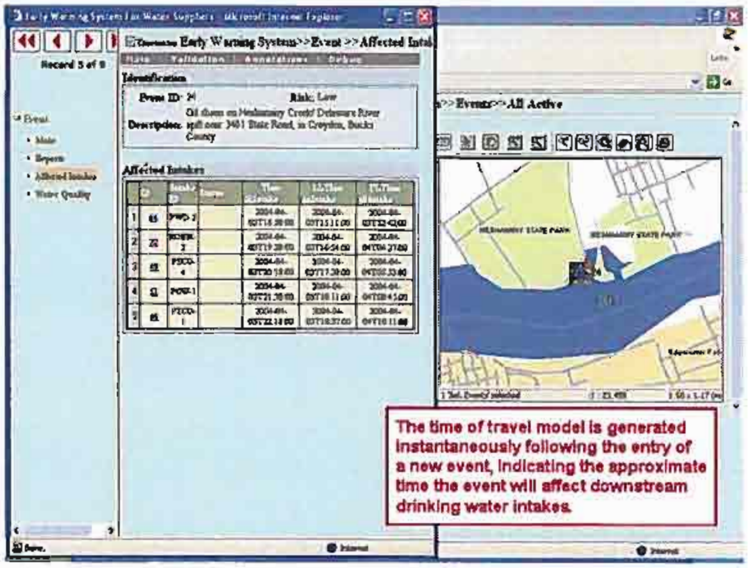

The charting tool enables users to chart water quality data with reference to contamination events to observe the effect of the event on water quality at specific locations.

**FIGURE 9** Example of Delaware Valley early warning system user interface screen for a hypothetical spill event—time-of-travel results



The time of travel model is generated instantaneously following the entry of a new event, indicating the approximate time the event will affect downstream drinking water intakes.

**Allegheny and Monongahela rivers.** The Allegheny and Monongahela rivers converge at Pittsburgh, Pa., where they form the Ohio River. The Allegheny River is 325 mi (523 km) long and drains 11,700 sq mi (30,303 km$^2$). There are 16 water suppliers on the Allegheny River serving 637,000 people. The Monongahela River is 128 mi (206 km) long and drains 7,400 sq mi

(19,166 $km^2$). The 15 water suppliers on the Monongahela main stem serve approximately 771,000 people, and 4 water suppliers on the Youghiogheny River tributary serve 201,000 people. A system of locks and dams on the rivers supports commercial navigation; reservoirs located in the watersheds provide flood control storage. Figure 11 shows the Ohio River Basin area with the Allegheny and Monongahela rivers highlighted.

As noted previously, ORSANCO has operated a regional EWS on the Ohio River for many years. This Organics Detection System, however, provides organics monitoring only on the extreme lower reaches of these two Ohio River tributaries (the Allegheny and Monongahela rivers). In January 2002, the PADEP approached ORSANCO requesting assistance in establishing regional EWSs on these rivers, and PADEP provided $800,000 funding for system design and startup. Meetings held with drinking water utilities drawing from the Allegheny and Monongahela rivers found overwhelming support for the development and operation of a regional EWS.

*System had to fit regional resources, capabilities.* Initially envisioned as an expansion of the ORSANCO Organics Detection System, the Allegheny and Monongahela EWS evolved into an integrated source water monitoring network that would consider multiple parameters and host a secure website for the distribution of near real-time source water quality data. As part of the initial data-gathering effort, a suitability and susceptibility analysis of the drinking water utilities was conducted to evaluate each facility's needs and resources. The utilities located along the two river systems are relatively small; approximately 70% of the Allegheny and Monongahela river utilities serve 12,000 or fewer customers, with some serving as few as 1,000. Because utility plant personnel are already multitasking in their daily work, the addition or installation of any monitoring equipment that required significant time to operate, maintain, or interpret would not be accepted or successful.

**FIGURE 10 Upper Mississippi River Basin**

*Source: USGS, 1999*

In contrast to some other developing regional EWSs, the Allegheny and Monongahela system focused on enhanced monitoring of source waters. In 2002, instrument tests evaluated available online technologies that would provide useful source water quality data, require minimal time to operate and maintain, and deliver readily interpretable results. Test results were favorable for four types of water quality monitoring instruments: (1) a multiparameter probe measuring temperature, pH, conductivity, dissolved oxygen, chlorophyll, and turbidity; (2) a fluorometer measuring hydrocarbons or chlorophyll; (3) a total organic carbon analyzer; and (4) a portable, autosampling purge-and-trap gas chromatograph with argon ionization detector. Data gathered from these instruments can be transmitted via the Internet to a project computer server, displayed near real time on the website and archived for later assessment. Operation and maintenance time for this equipment was anticipated to be less than 1 hour per week.

A key step to the acceptance of this instrumentation was a demonstration of the proposed instruments to the water utilities. This helped allay concerns regarding the technical nature of the work required and the time commitment for operation and maintenance. Utility representatives provided input about which instruments they would be interested in supporting at their facility. This information provided the basis for the location and distribution of the monitoring equipment along the two rivers. Currently the Allegheny and Monongahela EWS has 11 monitoring locations operating a total of 7 multiparameter probes, 5 gas chromatographs, 3 total organic carbon analyzers, and 1 online fluorometer.

Another key component of the project was to foster the development of communications networks among the utilities. For several years, a communications network has existed on the Monongahela River for distribution of spill reports and spill information to downstream utilities. However, no such communication network existed on the Allegheny River. To answer this need, the Allegheny River Communication Network was organized during meetings of the Allegheny River utilities. The purpose of the group is to facilitate the exchange of spill and other water quality information of interest and concern to the drinking water providers.

This project has achieved and exceeded its initial goals. A state-of-the-art regional early warning system has been established that provides enhanced source water quality monitoring for multiple parameters, a mechanism for the distribution of these data in near real time via the Internet was developed, and a new communications network was created to facilitate information exchange among drinking water utilities using a common source water.

**TABLE 1 Steering Committee for the Delaware Valley early warning system**

| Designated Voting Seats (Permanent) | Temporary Voting Seats (Annually Voted on by Membership) | Advisory Committee (Nonvoting) |
|---|---|---|
| Philadelphia (Pa.) Water Department | Trenton (N.J.) Water Works | Pennsylvania Department of Environmental Protection |
| Pennsylvania American Water Company (Hershey, Pa.) | Morrisville (Pa.) Municipal Authority | New Jersey Department of Environmental Protection |
| New Jersey American Water Company (Delran, N.J.) | Middlesex Water Company (Iselin, N.J.) | US Environmental Protection Agency |
| Aqua America Pennsylvania (Bryn Mawr, Pa.) | New Jersey Water Supply Authority (Clinton, N.J.) | Delaware River Basin Commission (West Trenton, N.J.) |
|  | City of Pottstown (Pa.) | US Geological Survey |

**Susquehanna River.** The main stem of the Susquehanna River flows 444 mi (715 km) from its headwaters at Otsego Lake in Cooperstown, N.Y., to the Chesapeake Bay. More than 20 public water systems within the Susquehanna Basin depend on the river as a source of drinking water; these systems serve in excess of 2.5 million people in New York, Pennsylvania, and Maryland. Twelve of these water suppliers draw from the main stem of the Susquehanna River in Pennsylvania. Figure 12 shows the Susquehanna River Basin and the location of some water suppliers participating in the EWS.

*Commission spearheaded EWS development.* Development of a regional EWS for these 12 water suppliers has been led by the Susquehanna River Basin Commission (SRBC), with the majority of funding provided by PADEP. In instigating the project, SRBC has taken a relatively progressive approach; many other regional EWSs have been developed because of requests from water suppliers to a basin commission (or association), as opposed to the basin commission initiating the effort. SRBC has a history of assisting water suppliers and has worked with Pennsylvania and Maryland since 1999 to develop Source Water Assessments (SWAs) required by the 1996 Amendments to the Safe Drinking Water Act. SWAs are designed to identify the susceptibility of water supplies to a variety of potential contamination sources and can provide information useful for establishment of source water protection and monitoring programs. SRBC also receives funds from USEPA to conduct water quality monitoring within its jurisdiction and assist with program coordination related to water quality issues.

*Project scope defined.* Initially, the EWS will extend only through the Pennsylvania part of the Susquehanna River Basin. However, SRBC and the states of New York and Maryland are engaged in discussions to extend the EWS into those jurisdictions.

The scope of work for developing this regional EWS entailed six major tasks in the first year of development:

- Task 1—establish a steering committee of different stakeholders.
- Task 2—establish an EWS project database.
- Task 3—establish a communications network that would coordinate large spills through the Pennsylvania Incident Response System and promote data-sharing by water utilities on a secure website.

**FIGURE 11 Allegheny and Monongahela rivers**

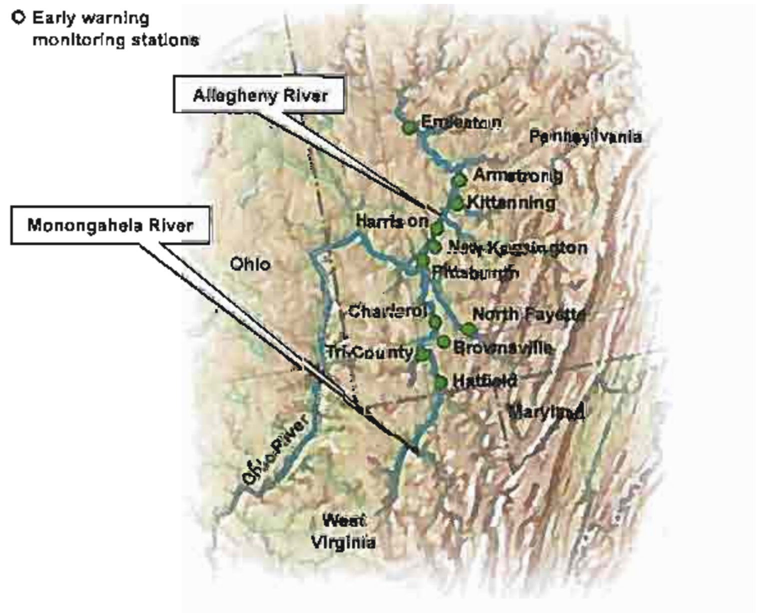
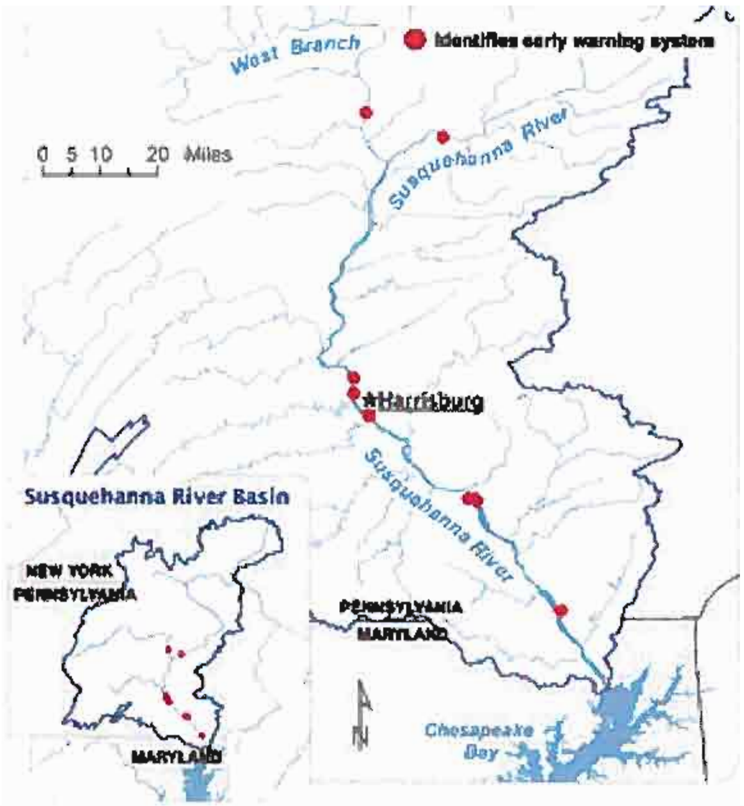


FIGURE 12 Susquehanna River Basin



- Task 4—design the full-scale monitoring system.
- Task 5—begin background work for development of a contaminant transport model.
- Task 6—assist water suppliers in connecting with other monitoring efforts (i.e., state and federal agency monitoring, citizen monitoring).

The initial phase of the project covered July 2002 through June 2003, during which time the framework for each of the six tasks was established. During the first year, three steering committee meetings were held, starting with a kickoff meeting in October 2002. Nine water suppliers have been active in the committee, assisting SRBC with decisions related to database and website design, monitoring data needs, emergency information needs, and contaminant information. Major efforts for the first year focused on establishing a website to serve as a hub for project communications and developing the monitoring resources needed to promote data exchanges and serve as indicator parameters for possible contamination events.

*Communications efforts take off.* A secure website was established and became operational in July 2003, allowing water suppliers to exchange water quality information and view emergency response bulletins and summaries distributed by PADEP. In addition, other information from project databases was made available through the website. Information includes stakeholder directories, contaminant inventories, project maps, Internet links to river flows and dam releases, and a time-of-travel calculator.

During the first year, development of the Susquehanna EWS focused on three baseline parameters: temperature, pH, and turbidity. By purchasing the equipment needed for online monitoring, SRBC increased the capabilities for five systems to provide real-time monitoring data for all three parameters. In addition, SRBC purchased a total organic carbon analyzer for another system that had existing online monitoring capabilities for the three base parameters. Beginning in July 2003, water suppliers started posting daily values to the website for temperature, pH, and turbidity. As of April 2004, three systems were posting data to the website at 4- to 6-hour intervals, and two more systems were expected to begin similar data posting soon.

*Future plans focus on funding, system enhancement.* In terms of future plans, SRBC will seek more stable funding for the operation and maintenance of the EWS and also investigate the potential for system enhancements and expansion. SRBC will be completing a study with USGS in December 2004 to characterize water quality and water velocity distributions across several transects of the Lower Susquehanna River. Because of the channel width and the presence of numerous islands and dams, the complex nature of the river presents challenges to establishing any sort of contaminant-tracking model. Study results should guide future model development efforts, as well as monitoring network enhancements.

## LESSONS LEARNED OFFER ROAD MAP TO FUTURE EWS DEVELOPMENT

The development of regional EWSs in the United States has provided several lessons that can be applied to the successful establishment of similar systems on other rivers. These lessons center on securing strong water supplier involvement from an early stage, overcoming institutional constraints, obtaining initial funding for leading the project, and dealing with the sometimes very slow pace of a project of this magnitude.

**Motivation for system development should not be driven by crisis.** A specific chemical spill or release has been the initial impetus for development of several EWSs throughout the world. However, prudent utilities will not wait for an incident to occur on other rivers to provide incentive but instead will establish a system before occurrence of a large-scale contamination incident.

**Stakeholder involvement can be the deciding factor in whether an EWS succeeds or fails.** Cooperation between the affected water users, appropriate agencies, governments, and other stakeholders is critical to the development and operation of a successful regional EWS. In many instances, a variety of political jurisdictions may be involved, and EWS project leaders would do well to include input from these sectors.

**Water supplier support is key.** The most important collaboration within a regional EWS is that of the water providers themselves. Experience has shown that water utilities are the driving force and backbone for development of almost all regional EWSs, and their support and involvement are essential to EWS formation and operation. Without utility participation and endorsement, the project will likely not gain the necessary support from the applicable environmental agencies.

**Limitations of water supplier resources must be recognized and reckoned with.** Even if participating water providers offer strong conceptual support, their limitations of available time and money may prove an obstacle, and some suppliers may find it difficult to initially participate to the degree that they would prefer. The daily responsibilities of providing an adequate and safe drinking water supply for their communities keep many utilities (especially the smaller ones) fully occupied. Because of this, utility involvement in a long-term project such as a regional EWS may be sporadic. The successful EWS recognizes these limitations and makes the most of those resources that are available.

**Individual leadership and institutional capacity must be developed.** Someone must take the initial action to organize stakeholders and start the planning process. An organization must be identified to coordinate and manage the overall system (it often helps to have a single organization serve as the overall system coordinator). Funding must be obtained and data-management and communications systems developed. The primary obstacle to successful development of regional EWSs are often these and other institutional considerations, as opposed to the technological limitations presented by the monitoring methods currently available. Strong stakeholder support, particularly from water suppliers and other water users, can help overcome these obstacles.

**Funding helps ensure project stability.** Adequate resources must be available in the early stages of the process to lead and perform the initial project work. Continued progress will depend on outside funding, and as many potential sources as possible should be considered. Involvement of key environmental agencies can help identify funding sources and secure funding for continued operations.

**Phased approach allows time for project to evolve.** A phased approach to launching a regional EWS helps ensure that planners and users are not overwhelmed by the potential complexity of the proposed system. Instead of trying to gather support for a complete advanced system, project leaders may want to start small to showcase EWS uses and benefits. The system can then be expanded and fine-tuned over time as conditions dictate.

**Salesmanship emphasizes obvious and not-so-obvious benefits of EWS.** Much of the early work in developing a regional EWS involves convincing various stakeholders that the system is needed and will provide substantial benefit in comparison with expected costs. It helps to clearly define the program and its uses so that beneficiaries understand what they'll be getting and what they will need to do to participate in and benefit from the system. It can also help to emphasize less apparent advantages such as the coordinated communication and notification aspects of an EWS program.

**Project team characteristics ultimately shape project outcome.** If a regional EWS undertaking is to be successful, the core team leading the project must encompass certain characteristics. The numerous stakeholders participating in such a process (especially the many regulatory agencies and water suppliers) and the extensive institutional considerations involved may present challenges in resolving various views, priorities, and expectations. At times, the process of developing an EWS can be quite slow. Members of the project team must exhibit and maintain a high degree of motivation, determination, enthusiasm, patience, and perseverance. With these traits, the team can help prevent the project from coming to a standstill and lead it on a continuing course toward success.

## WHAT DOES THE FUTURE HOLD FOR EARLY WARNING MONITORING?

The implementation of EWSs and regional EWSs within the United States is growing, and surveys by the AWWA Research Foundation indicate that most surface water users want these capabilities. It is anticipated that in the coming years, most major US river systems used as supplies for drinking water may develop these systems.

In the future, EWSs will likely become another part of routine activities for water systems in their multiple barrier approach. These systems will use extensively integrated information-management, data-management, and communication technologies that provide reliable and real-time information to all users as new technologies become available. The next generation of EWSs could include satellite communication, real-time monitoring technologies for pathogens as well as chemical and biowarfare agents, neural networks for predicting events based on current conditions, and web-based applications—all integrated with next-generation personal communication devices such as cell phones and personal digital assistants.

Stakeholder challenges to regional EWSs may significantly decrease as more systems are developed and demonstrate a degree of reliability, trust, cooperation, and value. Ultimately, regional EWSs that were developed individually could be tied together. For example, the systems for the Ohio River, Allegheny and Monongahela rivers, Lower Mississippi River, Upper Mississippi River, Delaware and Schuylkill rivers, and Susquehanna River could potentially be linked to create a "super-regional" EWS. This would enable individual regional systems to share relevant information, take advantage of administrative economies of scale, and work together to secure funding.

## ACKNOWLEDGMENT

Barbara L. Naramore of the Upper Mississippi River Basin Association was instrumental in implementing the Upper Mississippi early warning system and provided editorial assistance for this article. The authors thank Joe Hebelka and Joe Lee of the Pennsylvania Department of Environmental Protection for their role in developing regional early warning systems in Pennsylvania. Alan Vicory and the staff of the Ohio River Valley Water Sanitation Commission provided helpful guidance. The authors are indebted to the principal investigators of AWWA Research Foundation project 2527, including Walter M. Grayman, Rolf A. Deininger, and Richard M. Males, for their work investigating early warning systems worldwide. Review comments were provided by Mark W. LeChevallier of American Water. Partial funding was provided by the utility subsidiaries of American Water (headquartered in Voorhees, N.J.) and the City of Philadelphia (Pa.) Water Department.

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## FOOTNOTES

[1] Series 6 multiparameter probe, YSI Inc., Yellow Springs, Ohio

[2] Model TD-4100, Turner Designs Inc., Sunnyvale, Calif.

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BY RICHARD W. GULLICK, WALTER M. GRAYMAN, ROLF A. DEININGER, AND RICHARD M. MALES

# DESIGN OF Early Warning Monitoring Systems FOR SOURCE WATERS

**WITH EARLY WARNING MONITORING SYSTEMS, WATER PROVIDERS CAN RESPOND MORE QUICKLY AND EFFECTIVELY TO CONTAMINATION OF WATER SUPPLIES.**

Most raw drinking water sources are susceptible to a variety of disruptions in water quality as a result of accidental, intentional, or natural contamination. Rapid response to spills and other sudden pollution events is necessary to determine appropriate changes in drinking water treatment and operations in order to protect water consumers from potentially harmful contaminants, avoid treatment process upsets, and ensure compliance with environmental regulations. Early warning monitoring systems provide timely information on changes in source water quality so that knowledgeable response decisions can be made. Early warning systems can be a cost-effective mechanism for reducing risks, help boost public confidence in the water utility, and serve to encourage good practice and careful reporting on the part of dischargers.

Although the US Environmental Protection Agency (USEPA) does not mandate monitoring of raw water by water utilities, many utilities do so to some degree in order to (1) detect the existence of contaminants, (2) ascertain that existing treatment is adequate (and if not, to provide information that will help identify an appropriate improvement), and (3) provide real-time treatment process control. The monitoring data, however, are often limited regarding the number of parameters measured and the frequency of monitoring and may not be conducive to detecting spills and other sudden changes in water quality.

A 1999 survey of 153 water providers in the United States, Canada, and the United Kingdom found that a majority of utilities had experienced a significant source water contamination event in the past five years, adequate warning is not always available, the most serious perceived threats for the future are transportation accidents, and source water contamination is a significant issue that should be addressed through improved early warning systems (Grayman et al, 2001). The threats most commonly cited by drinking water utilities with intakes on rivers included spills of oil, petroleum, and chemical products from transportation accidents and pipeline and storage tank releases; insecticides and herbicides from agricultural runoff; and pathogens from untreated sewage discharges.

**This monitor uses a reed switch to detect whether the mussel's shell is open or closed. The mussels close their shells when sensitized by a toxicant.**

This article summarizes key results from two cooperative research projects (Grayman et al, 2001; Gullick, 2001). To examine the state of the art in early warning systems, these researchers surveyed utility practices and perceived needs for early warning and source water monitoring, performed a literature review of available monitoring methods, studied early warning systems around the world, examined case studies of monitoring practices at US utilities, developed a risk-based computer model for design and analysis of early warning systems, created a generic riverine contaminant transport model, and initiated development of an early warning monitoring network on the Upper Mississippi River. Though the principles of early warning monitoring apply to water quality changes from any source, this work focuses on source waters and does not directly address treated water in the distribution system or threats to the water supply infrastructure.

## SYSTEM COMPONENTS AND CHARACTERISTICS DEFINED

Early warning systems include a combination of continuous or frequent monitoring, other detection mechanisms, institutional arrangements, analysis tools, and response mechanisms. They can be used to detect rapid deterioration in water quality resulting from accidental or intentional discharges of toxic and hazardous materials near an intake (e.g., low probability/high impact events such as large-scale boat spills, pipeline breaks, industrial accidents, terrorist attacks). They are also useful for monitoring during extreme natural events (e.g., heavy rains and flooding, algal blooms) and somewhat predictable events (e.g., seasonal runoff of herbicides). Early warning systems are used mostly on riverine systems where water quality can change rapidly (see example scenario in Figure 1), less frequently for impoundments, and rarely for groundwaters.

**Multiple sampling ports on Germany's Rhine River are used to monitor water quality. The center two intakes monitor the general river water. The one close to shore represents and monitors the effluent of a large industrial complex located upstream on the same side of the river. The fourth intake is near the far shore to sample water that is primarily from an upstream tributary on that side of the river.**

**An ideal warning system features key components.** The scope of an early warning monitoring program will depend on site-specific characteristics. Systems vary from a single instrument at an intake to large river systems with networks of sophisticated monitoring stations combined with coordinated data management and information communication systems. Certain components, however, are generic to all good early warning systems and include the following:

- detection—a monitoring mechanism to detect pollution events and/or a public or self-reporting program,
- characterization—a means to confirm and more completely characterize the event,
- communication—a way to disseminate data to utility personnel and other decision-makers as well as to inform the public of response actions, and
- response—actions that minimize the potential effect of the contamination event.

An ideal early warning monitor would cover all threats, monitor continuously, provide warning in suffi-

**FIGURE 1** **Schematic example of an early warning system**

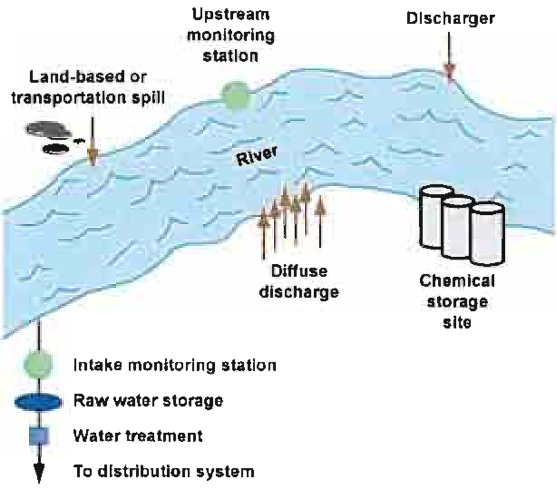
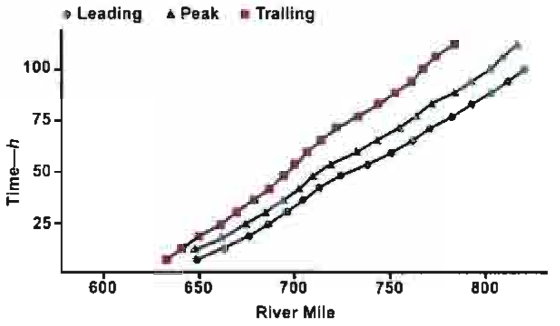


**FIGURE 2** **Example of riverine contaminant transport model output**



*Time of leading edge, peak, and trailing edge as predicted by model*

## Design Process and Components for Early Warning Monitoring Systems

- **Analysis of the need for early warning monitoring**
  - Preliminary vulnerability and susceptibility analysis
  - Review of available monitoring programs and data
- **Determination of program scope**
  - Selection of parameters to be monitored, monitoring methods, number and location of monitoring stations, and frequency of monitoring
  - Data management and interpretation
  - Cost–benefit analysis
- **Development of system organization and function**
  - Physical features
  - Administrative components
  - Response and communication plans
  - Funding
- **Implementation**
  - Monitoring program
  - Identification of response thresholds
  - Event confirmation procedures
  - Characterization of contamination
    - Data management, interpretation, and dissemination
    - Water quality modeling
  - Communication systems and plans
  - Response plans
- **System review and improvement**

cient time for action, give minimal false-positive or false-negative responses (such that the frequency of alarms is neither too high nor too low), be able to identify the source of contamination, be sensitive to water quality changes at regulatory levels, be reproducible and verifiable, require low skill level and training, allow remote operation, be affordable and robust, and function year-round (ILSI, 1999). Naturally, analysis of the system benefits, costs, and available resources may reduce the number of these characteristics that are applicable to specific situations, but the list provides guidance for development of such systems.

Monitoring techniques range from relatively simple online measurements of such parameters as pH and turbidity to video surveillance to advanced analytical instrumentation to the use of living organisms as bioalarms. Some methods (e.g., general water quality indicators such as bioalarms and dissolved oxygen [DO]) measure effects in the water, thus indicating that "something is not normal" but not necessarily what it is. Early warning monitors sometimes have less-sensitive detection levels than those of conventional monitoring, are often more qualitative and not compound-specific, and because they are concerned with identifying large changes in concentrations generally need less quality assurance/quality control (QA/ QC) than conventional or compliance monitoring.

### DESIGN SHOULD BE INCORPORATED INTO OVERALL SYSTEM

Early warning systems should be viewed, designed, and operated as an integral part of the operation of the overall water supply system (including source water quality protection programs and monitors, as well as intake, storage, treatment, and distribution system characteristics) in order to minimize the risks associated with degraded drinking water quality under various cost and technology constraints. The key components and steps in development of an early warning monitoring system are summarized in the sidebar on this page.

The type and scope of the system to be developed should be guided primarily by the relative potential risks (source water vulnerability/susceptibility assessment), cost–benefit analysis, availability of resources and technical capabilities, and current treatment capabilities. In some water supplies, continuous monitoring of a select few parameters at, or just upstream of, the intake may be sufficient. In other cases, particularly on busy commercial rivers with numerous intakes and potential contamination sources, a more extensive and coordinated network may be appropriate. Some water utilities use early warning systems to assess the quality of multiple source waters in order to be able to continuously use the highest quality source of those available. Reducing the time between occurrence of an event and implementation of response actions is critical and is accomplished through selection of appropriate detection methods; prompt data review, confirmation, and event characterization; efficient communication infrastructure; and rapid relaying of information to decision-makers. The design of early warning monitoring systems has been discussed in the literature (Grayman et al, 2001; Gullick, 2001; Foran & Brosnan, 2000; ILSI, 1999). Sanders and colleagues (1983) examined the process for water quality monitoring system design, including statistical analyses for optimizing monitoring locations and frequency.

**Vulnerability assessments help identify needs.** The types of land and water uses and activities (e.g., industries, agriculture, transportation, and other commercial enterprises) located near a water source can be used to identify potential contamination scenarios, rank their relative potential occurrence and effect, and prioritize a list of pollutants of concern to be considered for monitoring. The vulnerability assessment can be used to determine not only the requirements and scope of an early warning monitoring system but also the potential need for alternate raw water sources, treatment process alternatives, increased raw water or finished water storage capacity, and other system characteristics. Vulnerability assessments are already being performed for all US public water supply systems as part of the Source Water Assessment Programs (SWAPs) required of each state by the 1996 Safe Drinking Water Act (P.L. 104-182) (see www.epa.gov/safewater/protect.html). The SWAP requirements are separate and different from the security vulnerability assessments required of many water utilities by the US Bioterrorism Act of 2002 (P.L. 107-188) (see www.epa.gov./safewater/security/security_act.pdf).

**Detection mechanisms determined by site and system characteristics.** The decision of what parameters to monitor should be made on a site-specific basis and take into account both watershed and water supply system characteristics. The vulnerability assessment can provide a prioritized optimal list of parameters, which is then evaluated given practical, technical (including adequacy of available monitoring methods), resource, and budgetary constraints. A review of other existing monitoring programs for the source water (e.g., by state or federal agencies, industries, and other water suppliers) should be performed to capitalize on any potential synergies.

*Range of monitoring methods are available.* The primary mechanisms for detecting spills and other events include water quality monitors, self-reporting by the dischargers themselves, and sighting and reporting by the observing public or by public or private agencies and organizations. The most effective early warning systems combine all three means of detecting contamination events.

Because rapid, responsible self-reporting of spill events provides the most dependable detection method, regulations and protocols should be established and enforced to strongly encourage such actions. However, the existence of and compliance with such laws vary significantly around the world. Reporting by spill-response personnel and other governmental agencies and organizations is the most common means by which many US utilities learn of source water contamination events. Public reporting is most effective with larger contamination events that have observable results (e.g., fish kills, oil sheens, odor) and events in more heavily populated areas. The effectiveness of this method depends on a population that has been sensitized to reporting such events. In Japan, for example, public reporting is the most common early warning method.

Some utilities use daily or more frequent visual inspection of source waters to monitor for gross visible pollutants such as oil sheens and algal blooms. Video cameras are sometimes used to aid in visually monitoring intake water and also to monitor upstream areas where large-scale accidents could occur (e.g., bridge abutments, highway or railway overpasses). Images can be sent directly to the treatment plant control room, and computerized image analysis technologies can be used to detect certain changes in the video images and then issue an alarm when something changes in the picture. Use of video cameras at night can be problematic, of course, and lights may be necessary to provide better 24-hour visual monitoring.

Water quality monitors include physical, chemical, radioactive, and microbiological analyses that can identify and quantify either a specific water quality parameter or a surrogate parameter selected to provide a conservative indication of the presence of a more harmful but more difficult to analyze contaminant. When surrogates are used, an adequate site-specific correlation should be established with the parameter of primary concern. In addition, biomonitoring techniques that use living organisms can be helpful in detecting general changes in water quality and toxicity. Available monitoring technologies are discussed later.

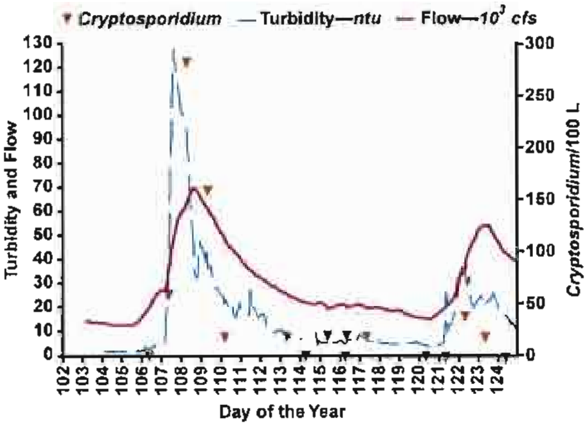
**The "smell bell" test is being performed here on a sample from the River Trent in the United Kingdom. The smell bell test is an inexpensive method of physical analysis but requires trained personnel with good noses and usually is not performed more than once per shift or once per day.**

*Several factors influence location of monitoring stations.* Monitoring systems should be installed far enough upstream from the point of water abstraction to allow for timely warning. On the other hand, monitoring stations located too far upstream will not provide coverage for pollution sources entering between the station and the intake. These somewhat conflicting considerations must be balanced with the available resources when water providers are determining the number and location of monitoring stations. If multiple water utilities use the same source (e.g., a river), they can take advantage of opportunities for cooperation and pooling of resources in terms of multiple monitoring locations.

Potential factors to consider in the selection of monitoring locations include the following:

- the location of potential contaminant sources,
- the river's flow rate (i.e., time of travel from major potential contamination sources to the intakes)
- the magnitude of mixing and dilution attributable to currents and hydrodynamic dispersion,
- consideration of all three spatial dimensions (e.g., how far upstream, where across the river, and how deep),

**FIGURE 3** Variation in turbidity, river flow, and *Cryptosporidium* concentrations during spring sampling in the Delaware River



*Source: LeChevallier et al, 1998*

- the type of contaminants (e.g., contaminants such as floating oils may determine monitor depth),
- the monitoring instruments' response time and frequency of analysis and data review,
- the nature of the treatment process (i.e., what can the processes handle, how much time is needed to make any potential adjustments),
- precautions to protect the instrumentation from the elements,
- security to prevent vandalism,
- access to electricity,
- means of telemetry (e.g., cellular telephone or radio versus need to acquire access to telephone lines), and
- access for monitor maintenance and upkeep.

Attention must also be given to the potential for mixing (or lack thereof) of contaminants both laterally and vertically in a river. Field tracer dye studies can be used to help elucidate river-mixing patterns between potential outfalls and water supply intake(s). With a small or well-mixed system, a single monitor near the river's center or bank may be sufficient. In other instances, multiple intakes may be necessary to adequately characterize water quality across the river.

***System efficacy depends on frequency of monitoring.*** The effectiveness of an early warning system improves as the monitoring frequency increases, and monitoring continuously via real-time online monitors is usually preferred. Longer times between samples can not only result in some short-duration events being missed but also delay the detection of the contamination event and the resulting mitigating actions. More-frequent analysis is suggested for monitors at intakes (given the lack of time between detection and entering the intake) as well as for faster rivers and rivers with lower dispersion. For upstream monitoring stations, the analysis frequency should take into consideration the contaminant travel time from the monitoring location to the intake.

***System only as reliable as its data.*** With any monitoring system, appropriate QA/QC measures are necessary to ensure reliability of the analytical data generated and foster confidence in the appropriateness of potential responses. Because early warning monitors are concerned with identifying substantial changes in concentrations, however, they generally require less QA/QC than conventional or compliance monitoring, and precision and consistency are more important than accuracy.

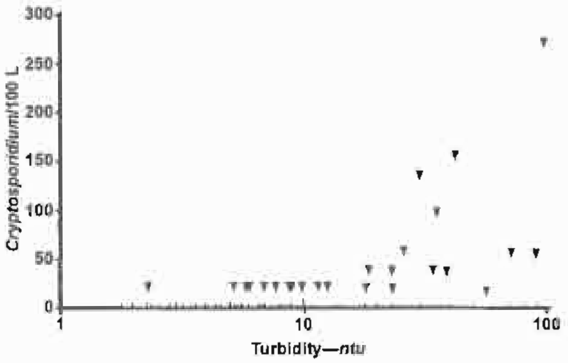
***Modern technology simplifies data transmission.*** Data from automated onsite or remote monitoring stations are usually easily transmitted for immediate use via modern electronic information transmission (telemetry) technologies such as telephone (wire and cellular), radio waves, and satellite-based communications systems. Telemetry devices are discussed in the AWWA manual for instrumentation and control (AWWA, 2001).

***Risk-based models facilitate system design and analysis.*** Spill events are highly probabilistic occurrences, but major spills are relatively rare. Minor spills are much more common yet generally have little effect. The recommended approach to designing and evaluating early warning monitoring is a systematic method that considers the highly variable, probabilistic nature of many aspects of the system. These aspects include the probability of spills, the behavior of monitoring equipment, variable hydrology, and the probability of obtaining information about spills independent of analytical monitoring.

Spill Risk, a risk-based model using Monte Carlo (probabilistic) simulation techniques, was developed to aid in the design and analysis of early warning monitoring systems (Grayman & Males, 2002; Grayman et al, 2001). This tool uses a one-dimensional advection–dispersion contaminant transport model for a single reach of river (no tributaries). Probabilities are assigned to different types of fixed and mobile spills and discharges. Numerous simulations are run with varying inputs, and the results are used to assess the impact reduction for a single water intake (in population exposure above preset limits) provided by a variety of alternative early warning system configurations. Specifically, the model can help to determine the optimum type, number, and location of monitors; the optimum frequency of analysis; and various response scenarios.

***Response thresholds determined by variety of factors.*** Every early warning monitoring system should include predetermined response thresholds (i.e., an increase in response above normal fluctuations from baseline levels) that warrant identification as a contamination event and trigger additional action such as confirmation procedures, additional investigation and characterization of the event, and assorted

FIGURE 4 Correlation of turbidity and *Cryptosporidium* in the Delaware River



*Source: LeChevallier et al, 1998*

prospective response actions. Selection of response thresholds should take into consideration such factors as

- historical patterns of water quality;
- the actual or perceived threat from various levels of contamination or events;
- the toxicity of the chemical or pathogen being monitored, with consideration given to regulatory limits and advisories;
- the nature and size of the population exposed;
- the ability of the treatment processes to remove the contaminant;
- the sensitivity and specificity of the monitoring method;
- the potential for false-positive or false-negative monitoring results; and
- the type and severity of action that might be taken if the trigger level is exceeded.

Response thresholds should be set at a reasonable level such that they don't occur either too frequently (too many alarms can be problematic) or too rarely (i.e., serious events are missed). A contaminant that could have severe public health effects would warrant a more stringent action trigger level than would a less harmful contaminant. Federal or state standards may be used as a guide, although in some cases, a lower value may be desirable; if existing treatment processes are efficient for that contaminant, then perhaps a concentration somewhat higher may be acceptable.

**Protocol needed to confirm initial monitoring results.** Initial detection results should be confirmed because false-positives may be associated with monitoring instrumentation or incorrect public reports. The confirmation process may include thoroughly checking the result's QA/QC, resampling and repeating the analysis, and performing more-accurate or more-specific alternative methods of analysis. Optimally, this step would not necessarily preclude or delay a necessary response action; any such delay should consider the immediacy of the situation, the potential magnitude of the event and corresponding possible effects (or perceived effects) on public health or the treatment systems, and the risks the water supplier is willing to take (if any), as well as other site-specific circumstances. If intakes can be closed with no substantial adverse ramifications, then it would be prudent to do so during the wait for event confirmation. To aid in confirmation, some advanced monitoring stations automatically take samples at fixed intervals and store these samples for a fixed period (e.g., 24 h); other stations are designed to take samples automatically when a monitor detects an unusual event. In either case, these samples can then be analyzed using standard tests to confirm and characterize the nature of the contaminant.

**Characterization of contamination guides response.** Characterization of a contamination event is imperative in order for the utility to predict with reasonable accuracy the event's effects on intake water quality over time. Contamination characterization is a six-step process:

- Step 1: Determine the specific contaminant(s) involved.
- Step 2: Identify the likely source of the contaminant (if unknown).
- Step 3: Determine the spatial and temporal variation in concentration in the source water.
- Step 4: Assess the dynamic behavior of the contaminant in the water body (mixing and decay behavior).
- Step 5: Predict the movement of the contaminant within the water body in order to predict both the time that the leading and trailing edges reach water intakes and the likely concentration.
- Step 6: Determine the effects on the waterway itself (e.g., fish kills).

Characterization of the contamination event is generally accomplished through sample collection, field and laboratory monitoring, instream tracking of the event, and use of mathematical models to predict the movement of the contaminants in the water body. Depending on the extent and severity of the event, the amount of field work and monitoring can vary significantly.

Predictions of the concentration–time–distance profile of a contaminant event can be developed to warn water users in advance of the time period when the contaminant will be at their intakes and what concentrations they will be subject to. Mathematical hydrodynamic contaminant transport models that are properly developed, calibrated, and operated can provide reasonable predictions in many cases. These models include a hydrological component that predicts contaminant transport via water flow and dispersion; often various contaminant fate processes are included as well. Models intended for use in rapid-response scenarios should be easy and quick to use, generate predictions with reasonable accuracy, and provide output that is easily interpreted. In addition to testing the model on a routine basis, water providers should establish protocols, train personnel, and set up a