

Revised Research Addendum after Peer Review

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Project ID and Title: (SN-17) Innovative Springshed Mapping for Trout Stream Management

I. Abstract:

Innovative identification and delineation of supply areas (springsheds) for springs serving as coldwater sources for modern and historic trout streams and assessing impacts on them from land and water development.

II. Background and hypothesis:

Trout streams depend on a steady supply of clean, cold water to exist. Minnesota's karst lands (Fig 1) contain 173 designated trout streams each of which is sourced from springs. Those trout springs are under increasing pressure from changing land use. Additional large groundwater withdrawals for energy production and other development loom in the future. Delineation of the recharge areas or springsheds of the trout springs is a crucial first step in the protection of the trout fisheries and the restoration of those that have been degraded.

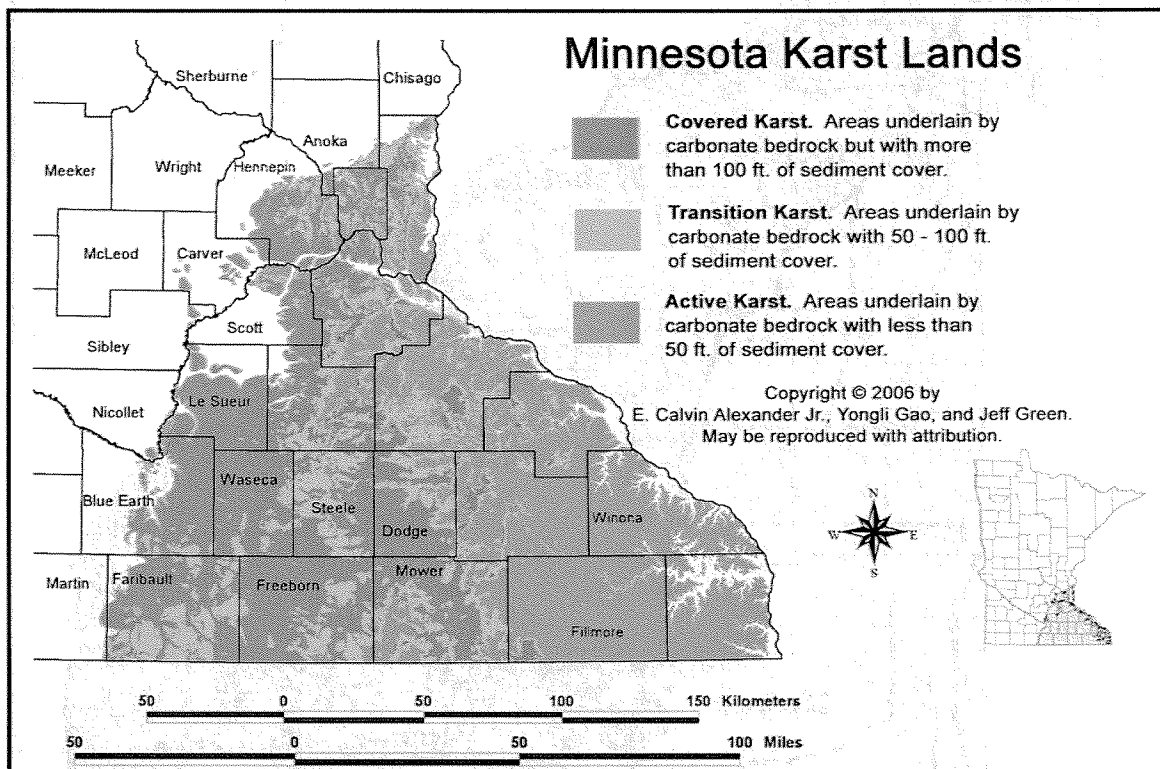


Figure 1. Study area.

Dye tracing techniques, the proven method for accurately delineating springsheds in karst, are the "gold standard" but are logistically difficult to apply at the regional scale. Dye trace work over the past three decades has documented springsheds for 14 of the 173 designated trout streams (8%). Fig. 2 shows the distribution of trout streams in the study area. The mapped

springsheds are indicated. Those springshed often bear little similarity to the surface watersheds feeding the trout streams and both sets of information are necessary. While

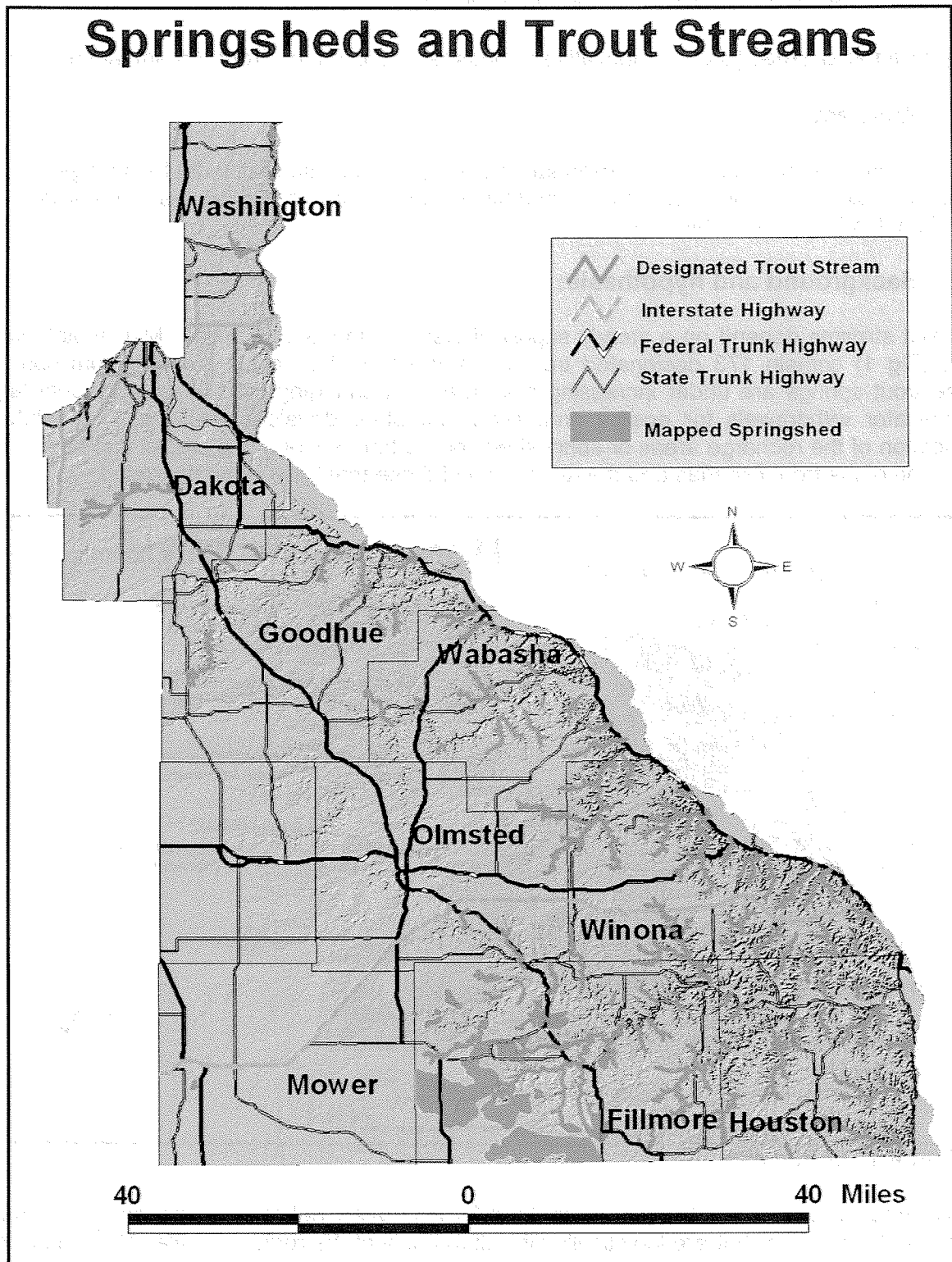


Figure 2. Trout streams in southeastern Minnesota.

information on the surface watersheds of each trout stream is available information on the springsheds is not. Development of supplemental springshed mapping tools is a critical component of extending springshed mapping to wider scales. Cost effective application of Best Management Practices to protect and improve the quantity and quality of water flowing from the trout spring will be contingent on an understanding of how groundwater is recharged in the springsheds.

The working hypothesis of this proposal is that springshed mapping can be accelerated beyond its historic pace.

III. Description of the methodology to be employed to carry out the proposed research.

Innovation in dye trace techniques, improved instrumentation and GIS technology for data handling and manipulation collectively permit more springsheds to be defined in a shorter amount of time. In addition, other hydrogeologic techniques, new mapping techniques and the availability of hydrogeologic information and data from other projects can synergistically expand the information obtainable through dye traces. Substantial amounts of information relevant to the hydrogeology of Minnesota trout streams has been and is being generated by other monitoring and mapping efforts that can provide constraints on the trout stream springsheds.

Using artificial additives (tracers) to track groundwater flow is a widely used tool in karst aquifer investigation. A tracer is added to the groundwater system via a sinkhole, sinking stream, or cave stream and then it is sampled for at those points, springs, where the groundwater system discharges to the surface. When done successfully, this point-to-point tracing technique provides a significant amount of information about the groundwater flow system. When point-to-point connections are known, they can be used to delineate the area that contributes water to a spring (springshed). If water samples are taken regularly during the tracing experiment, the groundwater time-of-travel, its rate of movement, can be determined. This information can then be used to evaluate the impacts of quarries and other land uses.

For this type of work, the tracer should be conservative, i.e. travel at approximately the same velocity as the water molecules. Fluorescent dyes are the preferred karst tracers because they are conservative, readily obtainable, non-toxic, and relatively simple to analyze. There are many fluorescent dyes available to use; through extensive field experiments only a few have proven suitable for groundwater tracing. This suitability is based on the tracer being recoverable from the water, having a low tendency to adsorb on to the aquifer material or suspended sediment in the water, and low toxicity to plants and animals.

For this study, the dyes used will be Eosine (CAS 17372-87-1), Rhodamine WT (CAS 37299-86-8), and Uranine C (CAS 518-47-8). Three dyes are used to allow us to trace from up to three different sinkholes at the same time. The traces will be designed to establish connections between recharge points (sinkholes and stream sinks) and discharge points (springs) and obtain groundwater flow velocities. As the point-to-point connections are established, we can then delineate the groundwater basin boundaries.

In addition to deliberately introduced tracers such as fluorescent dyes, a variety of naturally introduced or inadvertently introduced tracers can provide useful information about the springsheds of these trout streams. These "environmental" tracers include the dissolved cations and anions in the waters, stable and radioactive isotopes, dissolved organic compounds (both natural and anthropogenic), sediments, temperature and flow spike associated with recharge events. Some of these quantities are currently being monitored by other agencies. We hope to "mine" some existing data sets and acquire additional data.

As we have worked in southeast Minnesota, we have noted that springs have fluctuations in temperature, conductivity, and discharge. We intend to monitor temperature and conductivity in springs that are known to be directly connected to sinkholes and stream sinks. Those data will

be compared to other springs that do not have a proven connection. By comparing those data, we can begin to determine which classes of springs (emanating from the different bedrock types) are more likely to be directly connected which will guide future springshed mapping efforts.

Researchers in Kentucky have found that in each specific karst unit, the spring's base-flow discharge can be measured and plotted to develop a normalized base flow value. This number correlates with the area of the springshed. We will employ this technique in the Galena karst in areas where we have done extensive springshed mapping.

The bedrock aquifers comprising the springsheds of the trout stream change systematically from west to east across the study area. Three separate areas are the Galena Group springs, Prairie du Chien Group springs, and St. Lawrence-Franconia springs (Fig 3).

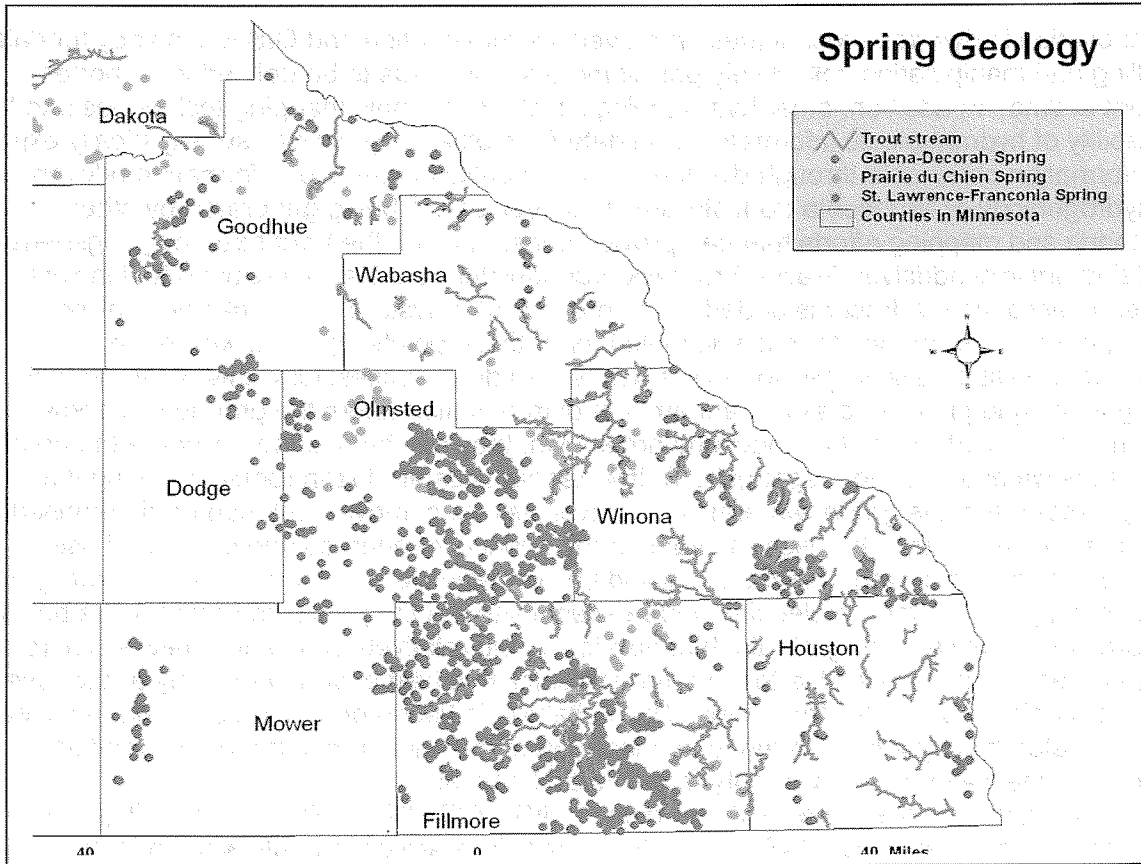


Figure 3. Trout Stream Geology.

The approach we will use to delineate springsheds will vary based on the geography. The first major area is the Galena Formation. The Galena is limestone that has numerous karst features in those areas where it has less than 50 feet of unconsolidated material over it. We have extensive experience using fluorescent dyes to delineate springsheds in the Galena Formation. That approach we will be used in this project. We will target both new areas that have not been investigated and will work to fill in the gaps between existing mapped springsheds.

The second major area is the Prairie du Chien Formation. This formation has surface karst features in varying degrees of density. Our previous work with fluorescent dyes has been moderately successful. For this project, we will continue with our use of fluorescent tracers. We

will also use temperature loggers to record temperature fluctuations in selected springs. These data will be compared to data from Prairie du Chien and Galena springs with known connections to surface karst features. This study of temperature flux will enable use to determine the degree of connection to surface karst and, combined with discharge information, potentially extrapolate springshed size.

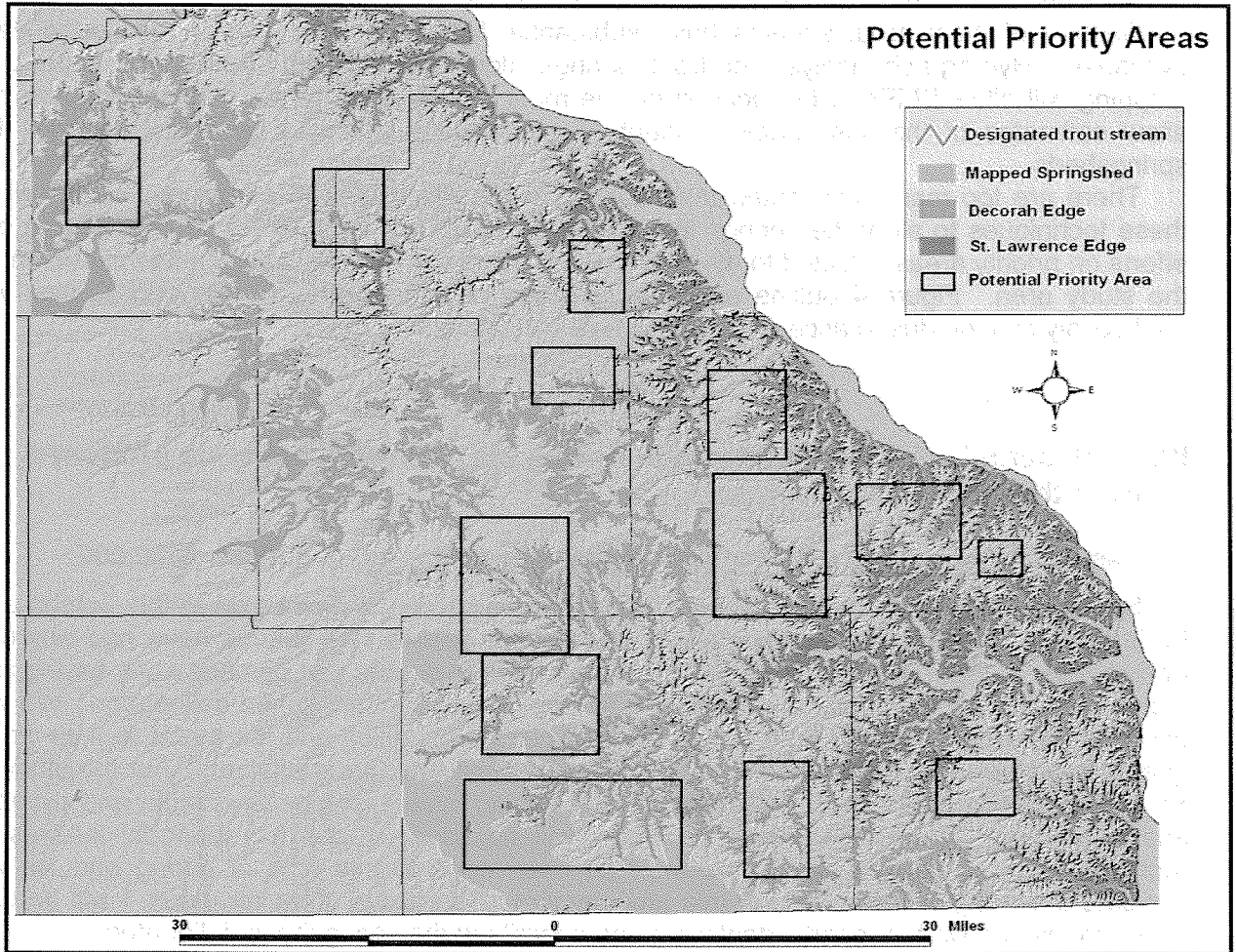


Figure 4. Potential Priority Areas.

The third major area is comprised of springs emanating from the St. Lawrence & Franconia Formations where those aquifers are exposed on the hillsides in the eastern part of the study area. Our observations in the area lead us to believe that these springs are connected at varying degrees to Prairie du Chien karst features. Our springshed mapping will include the use of fluorescent tracers. Temperature and discharge measurements will also be used. DNR Waters has discharge measurements for several of these springs. These data will be analyzed for trends. We also intend to use stable isotopes (hydrogen and oxygen) to look for seasonal influxes of recharge water. DNR records indicate that St. Lawrence-Franconia springs can have dramatic discharge fluctuations that appear to be seasonal. Isotope hydrology may allow us to fingerprint these waters; we can then sample other springs that are not monitored for discharge to determine if they are getting this seasonal flux. That, combined with karst feature locations, will allow us to begin to approximate the springsheds for these springs.

We will begin the process of Karst Landscape Unit mapping in western Fillmore County (an extension of the existing map of Mower County). A Karst Landscape Unit is a discrete three-dimensional bodies in which solution of the bedrock has resulted in the integration of surface water and groundwater. They are delineated based on bedrock type, depth to bedrock, topography, surface and subsurface hydrology, spring chemistry, and the distribution, landscape position, and type of surface and subsurface karst features.

Several of these trout streams have substantial flow and water quality monitoring data available. Hydrograph analysis of trout springs' flow coupled with Karst Landscape Unit mapping will allow BMPs to be focused on the most critical areas in the springsheds and will allow estimates of the sustainable amount of groundwater that can be extracted from the springsheds.

There are too many designated trout springs in the study area to permit application all of these techniques to all of the springs in a single biennium. We will therefore concentrate our efforts on priority areas selected to cover the entire range of hydrogeologic conditions present in the study area. Figure 4 outline an initial selection of priority areas. This prioritization will doubtlessly change due to access and other field conditions.

IV. Description of the results and/or products (deliverables) to be produced from the proposed research:

Result 1 Innovative Trout Springsheds Maps and Reports. Budget: \$160,000.

Springsheds that feed source springs of trout streams will be delineated in the Galena and Prairie du Chien karst lands. Only about 8% of trout stream springsheds have had any dye tracing done in them in the past 30 years. We propose to double that number while developing techniques and supplemental mapping tools for rapid accurate springsheds delineation. We will prioritize the watersheds for work based on their current condition and the threat to their water quality from current and proposed land usage and groundwater appropriations. For the study of St. Lawrence-Franconia springs we will use dye tracing, stable isotope (hydrogen and oxygen) and chemistry. The isotopes and chemistry will be used to look for seasonal influxes of recharge water. Virtually no dye tracing has been done to this type of spring and we will evaluate the utility of these tools in this environment. The deliverables for result 1 will be GIS based maps and written reports identifying and describing the springsheds delineated.

Result 2 Trout Springsheds Assessment Protocols. Budget: \$90,000.

Given a well-defined springsheds of a trout stream's source spring, the assessment of impacts of land use changes and new large water withdrawals and the offsetting improvements in recharge and water quality of the springs' flows require new protocols. Continuous flow and water quality information is critical to evaluate these competing processes. We propose to use data logger technology and Karst Landscape Unit mapping to develop protocols for karst hydrogeology-based springsheds assessment. The deliverables for result 2 will be reports describing the Springsheds Assessment Protocols for the springsheds analyzed.

Result 3 BMP Handbook for Trout Springsheds Budget: \$20,000.

Given well-defined springsheds and a karst hydrogeology-based springsheds assessment protocol, a critical examination of existing and new BMPs will be necessary for managers of

