APPENDIX 1
SCIENCE PLAN
February 2,2004

ISSUES: Sediment carried by storm water from large-scale land disturbance has a significant effect on the ecological health of Tennessee streams. Highway construction presents challenges to the protection of surface water that are typical of land disturbance in general, but also offers an opportunity for controlled study under a variety of environmental conditions. In the past, most studies of construction runoff have confirmed high concentrations of sediment, or impacts on aquatic life, or both. Some differences in sediment export can be related to physical characteristics that are determined by project location and alignment, but others may be determined by the nature of the disturbance and sediment control designs.

Studies of measures designed to limit sediment in construction runoff have focused mostly on controls applied at the outlet from the project areas, e.g. sedimentation ponds. The new context for this program of study is the commitment by the State to a more stringent application of erosion prevention and sediment control (EPSC) systems, integrated with the construction process over the entire site. The goal is to reduce sediment in construction runoff to near-background levels and eliminate significant impact on aquatic organisms. In this context, there is no uncontrolled runoff to study.

SCIENCE GOALS: The ultimate goal of this science plan is to understand how aquatic communities are affected by sediment associated with highway construction, the best ways to minimize effects of sediment through erosion and sediment controls, and the most effective ways to monitor for both disturbance and effect. The research objectives will be designed to cover the various requirements of the Amended Consent Order between the Departments of Transportation and Environment and Conservation (shown as Attachment #1), including support of the development of the statewide storm water management plan.

This science plan addresses four basic questions:

1. How is sediment export from construction sites related to geology, climate, highway design, and the type of erosion and sediment control measures applied?

2. How is sediment of various size classes transported downstream; where and for how long is it stored in the channel network?

3. What are the effects of increased sediment transport and deposition on aquatic communities?

4. Are there reliable indicators of sediment transport and deposition that correlate to responses in aquatic communities?

PROGRAM INITIATIVES: Answers to these questions can be approached through several broad program initiatives designed to implement and evaluate monitoring programs on highway construction projects across Tennessee and to evaluate how highway construction activities affect aquatic communities. Though the scope of these initiatives is generally limited to highway construction disturbances, the insights drawn from this work will contribute broadly to our understanding of the sources and control of sediment and the effects of sediment on aquatic communities across the state.

1. Quantify sediment export rates, over space and time, from disturbed, construction-affected and undisturbed reference basins across Tennessee.

Monitor a representative sample of small, disturbed basins over a range of geologic and hydrologic environmental conditions, and a variety of disturbance patterns and control conditions in and around highway construction projects. Monitor undisturbed reference basins (upstream and pre-disturbance sites) that are representative of geology and other physiographic factors within each region of the state. Identify contributing and controlling factors for those disturbed basins that exhibit above-background sediment export rates. Measure particle size distributions for sediment coming from disturbed and reference sites across Tennessee to determine the functional relation of particle size to sediment mobilization and export from various levels of disturbance and control.

2. Determine the movement of sediment from intermittent headwater streams and ditches draining highway construction areas downstream to perennial streams, including instream transport, deposition, and resuspension.

   Determine the sediment-size distribution over time in storm water and baseflow at selected sites on perennial streams below controlled highway construction and undisturbed reference basins to determine the distance of travel of various sediment size classes and the relation of sediment transport to flow regime. Measure sediment deposition and embeddedness along stream gradients extending from disturbed areas (measured on a scale of hundreds of square meters) to perennial streams (measured on a scale of square kilometers). Determine particle-size distributions of accumulated fine materials in channels and relate size distributions to basin and channel geomorphology and discharge characteristics. Compare overall sedimentation effects on reference and disturbed basins and determine which particle size fractions are true wash load, which are the result of remobilization of stored sediments, and what flow rates are necessary for remobilization.

3. Assess the effects of sediment transport and deposition associated with construction disturbance on fish and aquatic invertebrate communities.

   Characterize fish and invertebrate abundance and diversity in numerous reaches below construction-disturbed and undisturbed sites across Tennessee, accounting for differences in natural variability resulting from stream order, instream and riparian habitat, geology, and climate. Identify flow-related indicators of sediment storage and sediment transport (at stormflow or baseflow, for example) that correlate with biological indices. Evaluate the response of aquatic communities to thresholds of environmental stress.

4. Develop sediment-monitoring strategies that maximize the information about effectiveness of various erosion and sediment controls and likely effects on aquatic communities.

   Determine the precision with which a few samples can be used to estimate peak or average concentrations. Develop a strategy to optimize the time and/or stage of sample collection. Define the relations among turbidity, suspended-sediment concentration, and particle size distribution for Tennessee streams across various physiographic regions.

   Develop bed-material sampling methods to monitor sediment deposition and changes in the embeddedness of coarse substrates. Determine whether observed changes in bed conditions are related to changes in the particle-size distribution of suspended sediment.

Define the relations among turbidity, suspended-sediment concentration, and particle size distribution for Tennessee streams across various physiographic regions and over a range of flow conditions, durations, and seasons. Determine the effectiveness with which continuous turbidity monitoring can be used to estimate a continuous sediment concentration.

Determine the applicability of sediment rating curves to assessing the impact of highway construction and other land use on the sediment regime of streams. Develop and field test a simpler, low-maintenance, shallow-water sampler to more effectively monitor sediment exported from disturbed sites. Identify sediment-monitoring techniques and technology suitable for use by the private sector in meeting regulatory monitoring requirements. Such techniques would be suitable for standardization, and capable of being applied with assured quality in the absence of direct agency participation.

IMPLEMENTATION: Scientific activities described in each of the initiatives above will be implemented in a series of overlapping phases of study associated with specific highway construction projects across the state. Each study phase will provide an opportunity to incrementally add to the body of information and interpretation required addressing the science goals as a whole.

Attachment #2 describes the anticipated phases of this contract.

Attachment #3 is a sample Work Order. Work orders will be issued by the State throughout the term of the contract and during each phase described in Attachment #2. Work orders must be approved by the State prior to funding and implementation.

Attachment #4 is a sample USGS Joint Funding Agreement that will accompany each Work Order.

ATTACHMENT #2

PHASES OF WORK TO BE COMPLETED

Phase 1: Construction monitoring for sediment, turbidity, and rainfall on SR-840 from SR-100 to Bending Chestnut in Williamson County, Tennessee. Monitoring will begin with instrumentation of numerous sites located in and around SR-840 from SR-100 to Bending Chestnut. Data will be collected continuously at 6 stream gages and 4 rain gages, and water will be sampled at 53 sites during storm flow. A detail of specific monitoring activities planned is given in the sample Work Order (see Attachment #**3**)**.** Interpretive elements of analysis concerning data collected on this project segment (sediment export rates, characterization of downstream sediment propagation and storage, and development of sediment-monitoring strategies) will be included in future phases of work.

Other phases will include, but may not be limited to the following:

- Construction monitoring for sediment, turbidity and rainfall on SR-840 from Bending Chestnut to Thompson's Station Road similar to those proposed in the sample Work Order and as described in the Amended Consent Order.
- Research and synthesis to provide data and information for use in development of a Statewide Storm Water Management Plan by the State. Projects will include SR-840 from SR-100 to Bending Chestnut, SR-840 from Thompson's Station to SR-106, and at least 6 other highway projects selected by the State and the Survey. Studies will include evaluation of effectiveness of EPSC plans and usefulness of turbidity and suspended-sediment data collection and evaluation of levels of turbidity and suspended-sediment that should trigger evaluation and repair of EPSC measures as described in the Amended Consent Order. The research will be designed, at a minimum, to answer clearly designed questions to be established by the State and the Survey.
- Evaluation of highway construction on waters of the state and stream biota, including pre- and post-construction stream surveys, along SR-840 from Bending Chestnut to Thompson's Station and at least 7 other highway projects selected by the State and the Survey. The research shall, at a minimum, include research components described in the Amended Consent Order.

ATTACHMENT #3

SAMPLE WORK ORDER

NOTE: Each Work Order will include the following five sections:

1. Scope of Work
2. Deliverables
3. Disposition of Equipment
4. Personnel
5. Funding

Work Orders must be approved by the State prior to funding and implementation.

Work Order #1: Construction monitoring for sediment, turbidity, and rainfall on the SR-840 from SR 100 to Bending Chestnut in Williamson County, Tennessee

1. SCOPE OF WORK:

The geographic scope of this phase of study is the area affected by SR-840 from SR-100 to Bending Chestnut, together with nearby small-unaffected reference basins.

The work will begin (date) and continue until construction is complete and all parts of the disturbed area are stabilized.

The activities listed for this phase of the study will contribute to answering scientific questions about sediment movement and its effects on aquatic communities, but additional activities will be needed to address the scientific questions as these are defined in response to the provisions of the Amended Consent Order. In particular, the approach in this supplement does not address ecological monitoring activities.

TASKS:

A. Shallow-water siphoning sampler design

In this project it is important to sample storm flow from many treatment systems and small disturbed basins. Pumping samplers are well suited to sampling in small channels, but are expensive and cumbersome. The U-59 sampler is simple and cheap, but it samples at a minimum of about 20-cm above the bottom of the sample bottle. Many of the sampling points will have shallow flow over bedrock, and it would be preferable not to excavate holes for the U-59 to sit in. We propose to develop a sampler that can withdraw a water sample from flow no more than 8 cm in depth.

Several design considerations are involved. Water should be sampled from undisturbed flow (not in the wake of the sampler) about midway between the bed and surface. The flow velocity in the intake tube should be high enough to yield a representative sample in the clay and silt size ranges. The sampler should be simple, cheap, and durable. It should collect a large enough sample for analysis in a reasonably short time (ideally about 400-ml per minute). The sample container and siphon should be easy to clean.

Limitations of this sampler will be comparable to the limitations of the **U-59,** but may include additional imprecision resulting from sampling near the bed. Small-scale patterns of turbulence may place the intake in an area of depressed or elevated sediment concentration.

B. Continuous hydrologic monitoring at downstream integrator sites

Six stream gaging stations will be located downstream from the project at a scale that allows nearly all the flow from the site to be sampled in a few stream reaches. Drainage areas for integrator sites will range in size from 1 to 3 square miles. Streams will represent a variety of stable habitats suitable for diverse aquatic communities. These stations are approximately 1 to 2 miles downstream of road construction right-of-ways.

The combination of ecological data (fish and macroinvertebrates) and chemical data (suspended sediment, nutrients, ions, and temperature) collected at integrator sites will address if and how overall stream health is affected by road construction upstream of these sites. Discharge, turbidity, temperature, and rainfall data at the integrator sites will help determine loads and transport rates under various flow conditions.

The following parameters will be monitored and sampled at integrator stations (data will be available real time on-line):

- Continuous Stage Measurements with Discharge
- Continuous Turbidity Measurements
- Continuous Rainfall Data
- Continuous Temperature Measurements
- Continuous Specific Conductance
- Selected storm samples from automatic samples and siphoning samples will be analyzed for particle size and suspended sediment.

Integrator sites will be established at the following proposed locations:

- Kelly Creek at Sloan farm
- Copperas Branch near Sloan farm
- South Harpeth Creek at South Harpeth Creek Road
- Big Turnbull Creek at Liberty Road
- Locke Branch near Cassman Spring
- Younger Creek at Lampley Road (Background site – tentatively)

C. Real-time monitoring of rainfall on construction sites

Rainfall will be measured continuously at **4** mobile continuous-rainfall gages along the right-of-way. The 4 mobile rainfall stations will be moved during construction activities to the areas of maximum current land disturbance. All 10 continuous rain gages will report near-real-time rainfall amounts via satellite telemetry. This rainfall information will be available for review on the Tennessee USGS website (http://tn.water.usgs.gov/datapg.html).

Locations: The four mobile continuous rainfall monitoring stations will be established in the most active construction areas, and will be moved to accompany grading activities.

Equipment: Rainfall will be measured by tipping-bucket rain gauges (HIF 7014010 or equivalent). Data will be transferred by data collection platforms (DCP's) automatically at one-hour time intervals via GOES satellites to USGS servers.

Potential expansion of rain gage network: The 10 GOES rain stations are sufficient for most of the research objectives. It is possible that private-sector partners to better define rainfall depth

will install additional rain gages. Locations and methods will be reviewed by USGS, and if acceptable, data from these gages will be used to support research.

D. Sampling at disturbed and undisturbed indicator sites

Storm water will be sampled at 53 locations. These locations are much smaller scale than the continuously monitored locations, and have ephemeral or (where springs are present) intermittent flow. Crest-stage indicators will be installed at all of these stations, but because of small scale and access difficulty it isn't feasible to rate discharge. All water samples will be analyzed for suspended-sediment concentration and turbidity.

At about 35 of these stations, two siphoning samplers will sample the rising limb of the storm hydrograph. If it's not feasible to place siphoning samplers in the channel, single-sample pumping samplers (e.g. Global Water SS101) will be substituted. If an optimum level for sampling can be identified, one of the samplers may be removed.

At about 18 stations, multiple-sample pumping samplers will be used to characterize SSC and turbidity for the entire hydrograph. Most of these will be Global Water storm-water sampler SS201, which takes a sample on the rising limb, and pumps at regular intervals into a second bottle as long as the stage remains above a selected level. 24-bottle Isco and Sigma samplers will occupy some of these 18 stations.

Other 24-bottle Isco and Sigma samplers will be rotated among stations that don't have them. Generally the mobile 24-bottle samplers will follow the area of greatest land disturbance, and will be used to evaluate the efficacy of the sparser sampling.

The types of locations sampled can be divided into **4** categories:

- Outlets from treatment systems, carrying water that comes almost entirely from areas disturbed by construction. Some of these locations are at the downstream edge of the right of way (ROW) and others are inside the ROW.

- Unaffected basins.

- Combined outfalls, points where water from the construction area, mixed with water from upstream-unaffected basins, leaves the ROW.

- Downstream combined-flow sites with water from several treatment systems, mixed with water from unaffected areas downstream from the construction area. These sites are distinguished from the former category by potentially different timing of clean and dirty water in the hydrograph.

Treatment-system outlets within the ROW are designed to disperse their outflow in shallow flow over rough, porous material. Consequently, the 8 sample locations within the ROW will be selected in the field, subsequent to construction, at points where flow is relatively concentrated.

The initial target for sampling threshold is the stage typically resulting from a 0.5-inch rainfall. This sampling stage will have to be determined by trial and adjustment at most sampling stations, because drainage area and channel rating are not known, sampling stage may need to be seasonally adjusted. When the rain gauge network shows a rainfall of 0.5 inch or more, when downstream discharge rises proportionate to a rainfall of 0.5 inch or more, or when contractors and State personnel on site report widespread surface flow, the samplers will be visited and water samples will be analyzed.

Sampling trips will be conducted by one of the Survey investigators in partnership with three field assistants provided by the State. The State will also provide a four-wheel-drive vehicle large

enough to carry the field assistants and about 20 cubic feet of cargo. These visits will occur on the day after the rainfall threshold is exceeded.

Samples collected from the pumping and gravity samplers will be analyzed in the field or locally using the LISST-Portable laser-diffraction sediment size analyzer. Survey-specific QA/QC for this instrument will be conducted in accordance with manufacturer's recommendations, advice from other Survey users, and any available guidance from OSW, HIF, and FISP.

The Survey suspended-sediment concentration protocol (SSC) will be used as the calibration and quality-assurance standard for sediment concentration analysis. Until the precision and reliability of the LISSTinstrument has been established for the polymer-treated storm water of this project, all sediment samples will be sent to a Survey laboratory for SSC analysis.

If and when the LISSTinstrument is shown to give reliable and sufficiently precise suspended sediment concentration, its results will be used for most samples. A subset of 5 to 30 percent of sediment samples will be sent to a Survey laboratory for SSC analysis throughout the sampling period.

Samples collected from the pumping and gravity samplers will be analyzed for turbidity in the field or locally (e.g. at the onsite State trailer). Field analysis will use turbidity sensors, e.g. YSI 6136, or a Hach 2100P turbidimeter. Other equivalent instruments may be substituted, subject to TDEC approval. Turbidity sensors will be calibrated using formalizing standard suspensions as part of standard USGS QA/QC. Local turbidity analysis will use a Hach 2100N turbidimeter, in accordance with EPA method 2130B Turbidity. QA will ensure comparability of field results to the Hach 2100N results.

Isco (and Sigma) samplers will characterize the temporal changes in sediment through a storm hydrograph.

E. Sediment concentration, particle size distribution, and turbidity

Turbidity is not closely correlated with suspended-sediment concentration, because larger particles don't contribute to turbidity in proportion to their mass. In this project element, turbidity will be compared to sediment concentration and particle-size distribution to determine whether it is correlated with fine sediment. The effect of polymers (Chitosan, PAM) on measured turbidity and particle-size distribution will be quantified by using agitation and chemical deflocculation.

II. DELIVERABLES:

Raw data, as it becomes available, will be placed on a web site accessible to the State Departments of Transportation and Environment and Conservation. Data used in the analysis will be compiled into data reports and provided to the State Departments of Transportation and Environment and Conservation. Results of interpretative work will be included in formal Survey reports or journal articles.

June 30, 2004 -- A review of literature relevant to sediment monitoring, sediment transport, and sediment deposition downstream from construction.

June 30,2004 – An analysis of background turbidity for the SR-840 from SR 100 to Bending Chestnutproject site.

March 31, June 30, and September 30, 2004 – brief quarterly progress reports, including reviewed data.