PRACTICAL DATA COLLECTION: ESTABLISHING METHODS AND PROCEDURES FOR MEASURING WATER CLARITY AND TURBIDITY OF STORM WATER RUN-OFF FROM ACTIVE MAJOR HIGHWAY CONSTRUCTION SITES

RT 1022

Iowa Department of Transportation - Research & Technology Bureau

Rebecca Kauten, *University of Northern Iowa*

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Sponsored by the Iowa Department of Transportation and Federal Highway Administration

SPR: 90-00-RB37-012

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16 **Abstract**

In anticipation of regulation involving numeric turbidity limit at highway construction sites, research was done into the most appropriate, affordable methods for surface water monitoring. Measuring sediment concentration in streams may be conducted a number of ways. As part of a project funded by the Iowa Department of Transportation, several testing methods were explored to determine the most affordable, appropriate methods for data collection both in the field and in the lab. The primary purpose of the research was to determine the exchangeability of the acrylic transparency tube for water clarity analysis as compared to the turbidimeter.

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INTRODUCTION

In anticipation of federal regulatory enforcement involving numeric turbidity limits for effluent discharge from active construction sites, research was initiated by Iowa Department of Transportation (DOT) to determine appropriate, affordable methods for surface water monitoring. Measuring sediment concentration in surface water may be performed in a number of ways. As part of a project funded by the Iowa DOT, several testing methods were explored to determine the most affordable, appropriate methods for basic data collection both in the field and in a lab-based setting. The primary purpose of the research was to determine the exchangeability of the acrylic transparency tube for water clarity analysis as surrogate data for turbidity measurements using an electronic meter.

On-site data collection occurred through the 2012 and 2013 construction season on three major DOT construction sites in Polk and Bremer Counties. Discrete samples are collected from the adjacent stream after .25" rainfall events. Samples are also collected from "passive" stormwater collectors mounted on fence posts. Stream stage is being monitored by pressure transducers, and rainfall is recorded and reported based on the .25" threshold through an email-based alarm system. UNI Earth Science students assisted with lab analysis, comparing turbidimeter measurements with 60 centimeter transparency tube measurements of water clarity. On-site monitoring includes nitrogen and orthophosphorus, as well as habitat assessments based on IOWATER protocols.

For both scheduled and triggered storm event sampling, a linear regression analysis indicates a strong relationship between transparency measurements and turbidity. Samples were also tested and compared for other sediment concentration methods, including total solids and settleable solids, as both are relatively cost-effective methods for data on sediment concentration in water. Based on the results, the study recommends the use of acrylic transparency tubes as a surrogate for turbidity measurements when more sophisticated tools are unavailable. Transparency tubes can serve as a rapid-response means of data collection at a fraction of the cost.

CHAPTER 1

BACKGROUND

In December 2009, the U.S. Environmental Protection Agency (EPA) proposed effluent limitations guidelines (ELGs) to regulate the concentration of sediment suspended in surface water discharges from construction sites. The proposed numerical standard for effluent discharge concentrations of sediment was initially structured with the potential for regular water monitoring requirements and other qualitative analysis of stormwater-driven discharges from construction sites.

To date, no numerical standard exists as federal law for effluent discharge of sediment-laden water from an active construction site. After subsequent injunctions filed by the National Homebuilders Association and other stakeholder groups, EPA withdrew the numerical limit of 280 NTU (nephelometric turbidity units) from the administrative rule. However, all non-numerical guidelines remain intact.

The regulation, as originally issued on December 1, 2009, established requirements that reduce pollutants discharged from construction and development sites, including requirements for a subset of sites to comply with a numeric effluent limitation for turbidity. On November 5, 2010, EPA published a direct final rule and companion proposal staying the numeric turbidity limitation established by the December 2009 rule to correct a calculation error. The Agency received no adverse comments regarding the stay, and therefore, effective on January 4, 2011, requested data on the effectiveness of technologies in controlling turbidity in discharges from construction sites and information on other related issues. At the present date, no further progress has been made at the federal level regarding
either numerical water quality standards for sediment concentration, nor methods by which regulated bodies may collect data. In lieu of such guidance, yet understanding the need for appropriate data and analysis to manage water quality on highway construction sites, Iowa DOT initiated this project.

The results and recommendations derived from this study are meant to serve as a guideline for Iowa DOT as it considers implementing water quality monitoring on active construction sites. The information may also be shared with other regulated bodies considering sampling and analysis for sediment concentration in construction site runoff. Lastly, information within this project report may be shared with Federal Highway Administration or EPA as suggestions for methods and approaches to characterizing stormwater runoff from active road construction sites and adequately managing data collected from such locations.

INITIAL TIMELINE & SCOPE

In anticipation of regulation involving the initial, 2009 proposed numeric turbidity limit, Iowa DOT staff began collecting discrete water samples and testing for turbidity at several active construction sites. Initial training and data collection methods were based on tools and techniques used by the IOWATER volunteer water monitoring program, sponsored by the Iowa Department of Natural Resources (DNR). In 2010, initial training was provided by the principal investigator (PI), in conjunction with an existing surface water monitoring project sponsored by the Iowa DNR.

Due to the small amount of data collected during the 2011 construction season, DOT staff determined additional resources would be needed and requested research assistance. A request was made to the University of Northern Iowa to establish a project plan and strategy for collecting turbidity data from active, major highway construction sites as a means of establishing water monitoring protocols for practical, universal implementation. The initial scope of work spanned the 2012 and 2013 construction seasons.

The overall objective of this project has been to collect and study turbidity and water transparency data from active highway construction projects. Implementation consisted of the following initial activities:

1. Identify, perform and recommend water quality monitoring protocols to be used as a means of gathering site-specific data from active construction sites during and following rainfall events of 0.25 inches or more.
    - Initial literature review and update of existing information.
    - Identify monitoring sites for 2012 and 2013 construction seasons based on Iowa DOT project plans.
    - Collect soil and water samples and record data from sites following .25 inch rainfall events.
2. Develop appropriate documentation to allow for broad-scale reproduction on an agency-wide basis.
    - Compare turbidimeter measurement data with manual transparency measurements.
    - Establish distribution curve numbers based on a range of soil types.
    - Document evidence accordingly.sites following .25 inch rainfall events.

3. Produce instruction materials on proper techniques, data management and basic analysis.

   - Present initial and final results to TAC for further evaluation.

   - Summarize data and TAC conclusions.

   - Produce reference materials for Iowa DOT and subcontractor use during future event-based monitoring and data collection.

   - Share information with contracting agency and subcontractors as necessary.

EXPANDED OBJECTIVES

As a means of extending the existing project, sampling continued into the 2013 construction season, and included an additional site for data collection.

Weather alert systems were also evaluated as part of this project. Over the course of the two active construction seasons, the study compared the use of on-site weather stations, DOT Nexrad™ BridgeWatch, WeatherUnderground.com data, and triggered alerts from RainWave™, a contracted service for triggered rainfall events.

RESEARCH PLAN

Significant Variables: The project compares measurements taken with a turbidimeter and by manually reading water clarity levels using an acrylic transparency tube. Samples were collected following storm events of 0.25 inches or more from the following locations

- Discrete (grab) samples from areas of concentrated flow, if present.
- At multiple locations within the site based on locations of controls and input from DOT.
- At a single station of overall concentrated flow (discharge).
- Discrete samples upstream and downstream from sites adjacent to a water resource.
- Samples collected using rising stage samplers placed upstream and downstream from active construction sites.
- Soil samples taken from various sites for lab-based soils analysis.

Analytical/Statistical Procedures: Data collected using meters and manual measurementswere compared to determine distribution curves for corresponding values. Lab-based soils analysis was conducted as a means of modifying existing curve numbers for varying soil types. SYSTATTM statistical analysis software wasapplied to the project as a means of establishing distribution curve numbers and testing the validity of a relationship between transparency measurements and turbidity measurements both in the lab and in the field.

The University of Wisconsin Extension Service established an initial comparison table for NTU and transparency measurements (See Appendix 1). The chart is meant to serve as a basic resource and guide for determining water clarity by means of an acrylic transparency tube. The measurements are taken without taking local site conditions such as soil type and other watershed characteristics into account. In addition, subsoil characteristics found in the various geological regions of Iowa may produce dissimilar results when comparing turbidity and transparency measurements (See Appendix 2). By collecting soils data from multiple regions within Iowa, the initial work related to this reference chart may be expanded to include variation found within different Iowa subsoils.

Experimental/Testing: This project was intended to serve as an introduction for Iowa DOT staff and subcontractors to basic methods of collecting data using meters and manual measurements, and appropriate data management for relevant results. In addition, results may help establish methods, protocols and procedures for ongoing data collection from construction sites managed by Iowa DOT and its partners.

Evaluation Criteria: Data collected from rising stage samplers was compared to sample data collected from discrete, manual samples. In addition, lab-based analysis using a variety of soil types established appropriate distribution curve numbers for corresponding turbidity-to-transparency values.

Inspection/Survey: Engagement with Iowa DOT and construction site staff included the following:

- Initial site review and selection.
- Initial training and instruction of any staff involved.
- Monthly site visits for regular maintenance.
- Samples collected within 24 hours of .25 inch rainfall events.
- Data collected and analyzed over two construction seasons.
- Site information collected regarding types and locations of controls (including photographs) and status of work at time of site visits.

A technical advisory committee (TAC) included representatives from Iowa DOT Office of Construction and Materials, Office of Design, Research and Analytics, and Iowa DNR Watershed Monitoring and Assessment Section.

Controls: Rising stage samplers were installed above and below active construction sites located adjacent to Waters of the State (See Chapter 3). Discrete samples were collected within 24 hours of 0.25-inch storm events. Both rising stage samples and discrete (grab) samples were analyzed using turbidimeters and transparency tubes, as well as tested for additional parameters such as dissolved oxygen (DO), temperature and pH.

Material/Procedure Development: Tools used and data collected as part of this project are meant to assist with standardization of methods and protocols for collecting water quality data from active construction site stormwater runoff. An important goal of the project is to establish economical, relevant and easily-reproducible data collection and analysis methods.

CHAPTER 2

LITERATURE REVIEW

The following chapter describes various methods of measuring water clarity and water cloudiness, all in relation to sediment concentrations in surface water, as well as information on states initially researched to identify methods used for surface water data collection. Methods range from the use of an acrylic transparency tube, either in the lab or in the field, to lab-based methods such as total solids and settleable solids analysis. Such methods were explored as a means of thoroughly understanding both the objectives of each method used, as well as determining the most practical, appropriate and cost-effective means of collecting sample data rom active construction sites.

Sources for the literature review consisted of state stormwater manuals produced by the respective transportation agencies. When such resources did not exist, as in the case for Iowa and North Carolina, the default was to guidance provided by the state regulatory agency. The initial literature review found the State of Washington implementing the use of acrylic transparency tubes as a surrogate for turbidity measurements. Other states list turbidity as a sampling requirement, yet have limited to no information regarding methods and protocols for sampling. In addition, some states refer to total suspended solids (TSS) as a surrogate for turbidity. While TSS may serve as a surrogate for lab-based sampling and analysis, the method does not directly correlate to field-based conditions, as it does not take watershed characteristics into account. (Bannerman, personal communication, 2012). Furthermore, TSS measurements were established as a means of analyzing water samples taken from wastewater treatment facilities, within a controlled and secured environment. Because of these concerns, an effort was made to determine whether or not acrylic transparency tubes could serve as an initial data collection tool to monitor trends and basic information about discharge from active construction sites. Should further analysis be necessary, a turbidimeter may be put to use. See Table 1 and 2.

TABLE 1

State	Sampling Parameter(s) *derived from respective state regulatory agencies for stormwater management permits, inspections and programs.*
California	*Sedimentation/silt: Settable solids, total suspended solids, or suspended sedimentation concentration. Turbidity is also tested.*
Iowa	*Data not complete.*
Minnesota	*Total residual chlorine, conductivity, dissolved oxygen, pH, settable residue, salinity, sulfide, turbidity, temperature, and vector attraction reduction. Other parameters found in NPDES document 40 CFR, Part 136.*
North Carolina	*Total residual chlorine, conductivity, dissolved oxygen, pH, settable residue, salinity, sulfide, turbidity, temperature, and vector attraction reduction. Other parameters found in NPDES document 40 CFR, Part 136.*
Washington	*Turbidity, transparency, and pH.*

LITERATURE REVIEW

TABLE 2

State	Sampling Methodology	Analysis
California	*Sample downstream from the last point of discharge, upstream of direct discharge, and immediately down gradient of run-off point. All equipment should be clean and calibrated. All equipment and sample bottles (ordered from an analytical lab) should be chemical resistant. Five samples should be taken up-stream, downstream, and one sample at run-in locations for the lab to make a composite, representative sample.*	*Either done in the field or in an analytical laboratory. Establish a background concentration (control) to compare to the results of events. Duplicate, blank and MS/MSD samples should be used for possible contamination as well as accuracy and precision results.*
Iowa	*Grab and composite samples.*	*Data not complete.*
Minnesota	*Data not complete.*	*Compare results with standards established by EPA (280 NTU) which can be found in Minn. R. 7050.0221 - 7050.0227 and 7053*
North Carolina	*Data not complete.*	*Data not complete.*
Washington	*Grab sampling for representative data.*	*Either use a lab or collect field data. Turbidity should be between 26-249 NTU, transparency between 7-32cm, and pH between 6.5 and 8.5*

With limited guidance available from existing state transportation agency stormwater sampling manuals, the methods for using an acrylic transparency tube were selected as a cost-effective means of gathering data from Iowa DOT sample sites.

TRANSPARENCY TUBE

According to previous research performed by the Principal Investigator (Kauten, 2009) manual transparency measurements may be the quickest and most affordable means of collecting basic water quality data from an active construction site. The measurement generates a baseline understanding of water clarity during weekly site inspections. Transparency tubes may also be used during triggered sampling events after storms as a means of rapidly collecting samples for basic understanding of site conditions. However, transparency tube measurements are not intended to serve as a 1:1 surrogate when comparing accuracy levels between turbidimeter measurements and transparency tube results. Should a higher level of accuracy be required for a sample on a given site, then a meter or lab analysis should be considered to reinforce the initial data. However, as an alternative to no means of sampling at all, an acrylic transparency tube can serve as an appropriate, cost-effective tool for basic data collection.

As a primary focus for this project, acrylic transparency tubes were used both in the field and in the lab for testing purposes. Data collected was compared with samples tested with a nephelometric turbidimeter.

Previous research compares the Australian turbidity tube and UWEX-WAV turbidity tube to a nephelometer (Fermanich, 1997). The Australian turbidity tube, or sediment stick, is similar to the acrylic transparency tube (Water Monitoring Equipment and Supplies). The UWEX-WAV tube was made from fluorescent light tube protectors. The sample in the UWEX-WAV tube was a standard formazin solution (K. Stepenuk, personal communication, December 3, 2013). The solution in the nephelometer and Australian turbidity tube were not specified. The confidence of both tubes was between 0.99 and 1.0 when compared to the nephelometer. A conversion chart (inches to NTUs) was then created based on the UWEX-WAV results (Fermanich. 1998).

The study uses standard formazin solution and homemade transparencytubes, which may not reflect results from field data. The conversion chart that was created from this study would be used for actual surface water samples, which behaves differently than formazin solution (Van Nieuwenhuijzen, A. & Van der Graaf, J., 2011). Also, the UWEX-WAV tube was makeshift and not standardized. By using actual surface water samples with a manufactured acrylic transparency tube, an accurate comparison can be made between the tube and turbidimeter

For the purposes of this study, pre-fabricated transparency tubes, field samples, and a turbidimeter calibrated using formazin standards were utilized, and measurements taken were from actual field samples. No fabricated samples were tested as a part of this study. Had this been done, more samples could have been tested. However, due to budgetary and scheduling constraints, the focus was on field-based samples as a means of reflecting a more “real world” data set.

Two other tests were conducted as a part of this study: Total Solids and Settleable Solids. The purpose of including these two tests was to verify the need for rapid, simple tools that work well in the field, as compared to lab-based analysis. While the higher degree of accuracy may be a trade-off, the result is basic data to measure trends and potentially trigger corrective action if conditions appear to change after storm events.

TOTAL SOLIDS

Total solids is an analysis used to find the soil concentation in a given volume of water. According to Minet, Laloy, Lambot, and Vanclooster (2011), soil moisture prior to rainfall is a key factor in determining the runoff due to its effects on infiltration capacities. Soils that are poorly permeable or during high intensity rainfalls yield an unpredictable runoff response. Soil moisture data from similar sites is recommended before and after rainfall events to help determine sediment concentration within the stream. Knowing about soil moisture and soil types could help a construction site be better informed when making their BMP decisions.

Total solids analysis was performed on both water and soil samples collected as part of this project. The objective was to determine whether or not soil moisture played a role in transparency or turbidity levels measured from field samples. Because the relationship was not found to have statistical significance, it was discontinued midway through the project.

SETTABLE SOLIDS

Settlable solids are useful data when samples are highly turbid. In the turbidimeter used (HACH 1200Q), samples containing over 1000 NTU's are not read accurately. If the samples are diluted, they may become a non-representative sub-sample. Another problem with reliance upon turbidimeter measurements at high NTU readings relates to the variability of particle size and impacts to light refraction. Smaller particles scatter light more uniformly, whereas larger soil particles may lead to inconsistent measurements. Many highly turbid samples collected during the project contained large debris particles, which justified further analysis. Water color and temperature, which also varies widely per sample, also has an effect on a turbidimeter. In the acrylic transparency tube, sample readings that are less than 5 cm are not readable. Both particle size and water color affect the reliability of the acrylic transparency tube (Pavanelli & Bigi, 2005). Therefore, it is reasonable to use the Settlable Solids test on samples that are highly turbid to generate a more accurate measurement of sediment concentration. Furthermore, the relation of Settlable Solid Concentration and turbidity are interchangeable values (Bayram, Kankal, & Hizir, 2011).

There are two main ways to perform a Settleable Solids test. Both ways need one liter of water to sample and an Imhoff cone set for analysis. The sample should be tested within 30 minutes of reception as to avoid altered measurements due to anaerobic activity within the sample. The first method inverts the sample until uniformly mixed in the liquid and then pour into the cone. After 45 minutes, the amount of settled solid in the cone is measured by depth, in milliliters (mL). The sample is then stirred and measured again after fifteen minutes. The final settled solid depth at the bottom of the cone is then recorded.

The second method inverts and pours the sample after mixing and waiting one hour to take the settled solid measurement from the cone. The sample is then stirred and left still for 24 hours before the final volume is recorded. Pavanelli & Bigi have found this method to provide a high degree of reliability (2005). However, due to the length of time required to take the measurement, the method may not be appropriate for rapid response on active construction sites.

Both testing methods work well for lab-based settings and standardized samples, such as silica or other materials. However, the methods do incur a higher margin of error when testing field-based samples from construction sites, rivers and streams. Also, while the settleable solids measurements may generate a more accurate measurement of sediment concentration at higher turbidity levels, this information may be superfluous, assuming for effluent limitations. If the concentration level has already potentially exceeded a set threshold, this information may only be necessary if assessing for total soil loss or punitive damages as a result of such high sediment concentrations in construction site runoff.

CHAPTER 3

FIELD AND LAB-BASED DATA COLLECTION

Four highway construction sites in three Iowa counties were chosen for stream monitoring throughout the course of this project. Sites located in Polk (Ank) and Bremer (Wav) Counties were categorized as sites with final grading and post-construction activities. Sites located in Buchanan (Buch) and Polk (WDMG) Counties were active construction sites. Table 3 shows the locations of all eight sites. The sites are separated further into "upstream" and "downstream" locations. Upstream indicates that samples and assessments were taken upstream from the construction site. Downstream indicates samples and assessments were taken downstream from the site. At each location one 1000mL and one 500mL water sample was collected and one 20g soil sample. In order to test nutrient levels more thoroughly through the State Hygienic Lab, one 250ml water sample was collected each at WavUp, WavDown, AnkUp and AnkDown.

TABLE 3: SITE LOCATION DETAILS

County	Name	Nearby Water Bodies	Coordinates
Polk	*AnkUp* *AnkDown*	*Otter Creek* *Otter Creek*	*X: 452538.766827533, Y: 4623934.785369571* *X: 452538.766827533, Y: 4623924.731182796*
Buchanan	*BuchUp* *BuchDown*	*Bear Creek* *Bear Creek*	*X: 591599.0178647017, Y: 4692396.124375582* *X: 591294.2172551005, Y: 4692209.8573363805*
Bremer	*WavUp* *WavDown*	*Quarter Section Creek* *Quarter Section Creek*	*X: 554305.9224451779, Y: 4729594.763356195* *X: 554265.1765303528, Y: 4729598.467530269*
Polk	*WDMGUp* *WDMGDown*	*Racoon River* *Racoon River*	*X: 435288.1635763266, Y: 4598884.5144356955* *X: 435398.2304631271, Y: 4598863.347726695*

RISING STAGE SAMPLERS

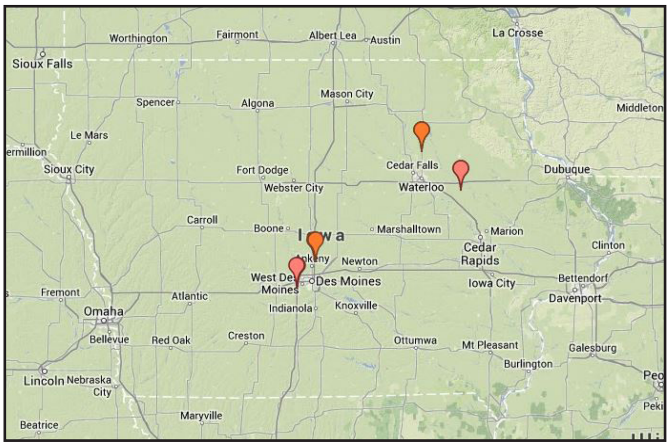

Figure 1 – General map of sites

Rising stage samplers, or passive samplers, consist of two Nalgene™ first flush sample bottles secured to a post with "shoulder" (where the curve begins in the bottle) at the water line, and the second bottle "shoulder" at the mouth (the opening of the bottle) of the first one (Figure 3). As it happens, the length of the bottle neck is exactly three inches from the shoulder to the intake. In total, both bottles receive diffused samples from the first six inches of rising water in the stream during high rainfall events, with the lower bottle of the two filling first.

Nalgene rising stage samplers were installed in pairs to collect aggregated samples at each location in Polk County (four total). The Nalgene first-flush sample bottle consists of a wide-mouth 1000ml Teflon sample bottles with a plastic "turban-shaped" attachment to allow for both buoyancy as well as inflow of water from the top of the bottle. Within the top, a gravity-based system allows water to slowly filter through the opening. A hollow plastic ball floats to the top of the three-inch tall bottle neck and seals off the top once the bottle is full. By installing two bottles at both upstream and downstream locations for each sample site, the first six inches of stage rise in the stream may be sampled during an initial storm event. (Figure 2).these two tests was to verify the need for rapid, simple tools that work well in the field, as compared to lab-based analysis. While the higher degree of accuracy may be a trade-off, the result is basic data to measure trends and potentially trigger corrective action if conditions appear to change after storm events.

Figure 2 – Rising stage sampler bottle

Figure 3 – Assembled rising stage sampler

ADVANTAGES OF RISING STAGE SAMPLERS

The price for assembling upstream and downstream samplers using the Nalgene bottles and a steel fence post ranges from $200.00 to $250.00, depending on how many bottles are purchased for replacement. The perforated filter collects more of an aggregated sample over time than simply having a one-liter bottle fill at the moment the stream stage rises. The plastic bottles are rugged, and all parts can be cleaned and sterilized for multiple uses.

DISADVANTAGES OF RISING STAGE SAMPLERS

The degree of accuracy for samples collected is quite limited, because there is no way to precisely calibrate the devices to ensure samples collected truly align with the rise and fall of the hydrograph. Comprised of plastic, the bottles are not acceptable materials for sampling constituents such as hydrocarbons or other volatile chemicals. Should glass bottles be used, they run the risk of breakage due to floating debris in high water.

SUMMARY AND RECOMMENDATION FOR FURTHER USE

While not ideal for a high degree of accuracy and precision, the two-bottle rising-stage sampler system provides a rugged, affordable method for upstream and downstream sample and data collection. Automated sampling equipment such as a Teledyne ISCO™ composite sampling device are valued at $10,000.00 to $12,000.00 per unit (Skopec, personal communication, 2013.) Compared to the cost of automated sampling equipment, and labor requirements for calibration and maintenance, this more basic approach is recommended for initial implementation. Should a higher level of sampling and data accuracy be required, these methods may not be adequate. However, as no other guidance exists from state or federal regulatory agencies, this may prove an adequate, if not effective sampling method.

WEATHER DATA

Because a significant portion of samples collected during the project were triggered by storm events, it was critical to ensure proper timing of such collection. The initial goal was to have alarms trigger sampling, which would then be conducted within 24 hours of the triggered storm event.

On-site weather stations were initially utilized for this purpose. In 2012, Davis™ VantageVue wireless weather stations were purchased for use on project sites. Lack of consistent access to electricity and internet connections complicated the use of these stations. Furthermore, the cellular phone carrier that Davis contracts with does not provide adequate service for Iowa, particularly rural areas where much of the construction occurred during the project. This included rural sites, as well as the West Des Moines site, which was located just outside the secondary carrier's coverage map.

The coverage for the mobile carrier service is depicted in Figure 4. The light pink area indicates coverage by T-Mobile, while the darker pink areas indicate coverage from a local carrier as a sub-contracted partner for the company. Because it is not directly operated by the original carrier, signal strength varies and, in most cases where the sites were located, there was no signal at all.

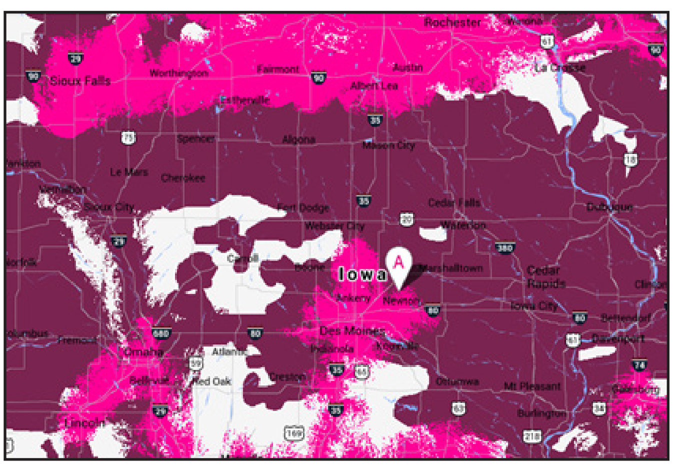

Figure 4: Coverage map for Davis Weather Station mobile network

In 2012, Iowa DOT implemented BridgeWatch software as a means of collecting accurate rainfall data near bridges. BridgeWatch, formerly ScourWatch, is manufactured by U.S. Engineering Solutions (USES) and is a real-time web-based alert program that can be customized according to the users' needs (U.S. Engineering Solutions, 2013, U.S. Engineering Solutions Cooperation, 2008) (Figure 5). The system can be populated with inventory data, personnel contact information, and structure specific thresholds to monitor for environmental conditions such as accumulated precipitation, increased river flows, hurricane induced tidal surge, and seismic events (Baribault & Scannell, 2010).

The method for collecting general data are based on national sources such as NEXRAD radar, meteorologic, hydrologic, oceanographic, and seismologic data. More defined sources are also used such as local or mobile meters, gauges, and other sensing devices (U.S. Engineering Solutions Cooperation, 2008). Precipitation data is collected from National Oceanic & Atmospheric Agency (NOAA,) U.S. Geological Survey (USGS), National Weather Service National Radar Data (NWS NEXRAD), and Natural Resource Conservation Service (NRCS) (Reese, 2009). A major benefit of this program is that it provides a historic archive of flood events and event performance (U.S. Engineering Solutions, 2013). Typically rainfall readings can be done every 1, 3, 6, 12, and 24 hours (D. Claman, personal communication, October 8, 2013). Alerts are sent via email, pager, fax, or text message when thresholds are met for specified locations. When purchased for the state of Iowa, the cost of the software system was $100,000 with an additional $75,000 in annual maintenance fees (D. Claman, personal communication, October 8, 2013). The general audience for this system is construction, engineering, and government services. Important clients include Connecticut, Indiana, Tennessee and Georgia Departments of Transportation, as well as Oregon Department of Natural Resources, and Natural Resource Conservation Service, (U.S. Engineering Solutions, 2013).

WEATHER DATA

From: <IABridgewatch@bridgewatch.us>
Date: Sun, Dec 22, 2013 at 3:57 AM
Subject: NEXRAD Warning
To: rebecca.kauten@uni.edu

25 year bridges: 7769.0-035 on null(NPDES) Garage: null

Warning Level
25 yr event
NEXRAD Product Type: Rainfall Twelve Hour(KDMX)
BIN: 7769.0-035
Location: Polk I-35 MP 69.0
Classification: NPDES
Garage Assignment: null
County: Polk County
Time: 2013-12-22 03:42:56.0
Exceeding Threshold: Warning Level 0.25 inches (11 hours)

From: <IABridgewatch@bridgewatch.us>
Date: Sun, Dec 22, 2013 at 4:52 AM
Subject: NEXRAD Warning
To: rebecca.kauten@uni.edu

25 year bridges: 1034.9-150 on null(NPDES) Garage: null

Warning Level
25 yr event
NEXRAD Product Type: Rainfall Twelve Hour(KDMX)
BIN: 1034.9-150
Location: Buchanan IA150 MP 34.9
Classification: NPDES
Garage Assignment: null
County: Buchanan County
Time: 2013-12-22 04:40:31.0

Exceeding Threshold: Warning Level 0.25 inches (12 hours)

Figure 5: BridgeWatch email alert example.

As an alternative to both the on-site weather stations and the BridgeWatch system, service for a web-based weather monitoring system known as RainWave™ was purchased to trigger rainfall alerts for the project sites. The system uses proprietary software and Doppler radar sites to track rainfall in designated areas based on a GIS network of triangulated weather stations and real-time rainfall data. Alerts were triggered when rainfall over 24 hours, from midnight to midnight, exceeded 0.25 inches. The alerts are sent via email along with a monthly rainfall report (RainWave, 2013). Cost was $250 for initial setup and $25 per month, per site.

For purposes of the project, data from BridgeWatch software was used for Buchanan, Bremer, and Polk County sites. Waverly and West Des Moines sites were additionally set up to use RainWave software. Below is the summary of alerts and events for September 2013 (Table 4, Table 5 and Table 6). Weatherunderground.com and NOAA.gov are the standard sources used for rainfall information.

TABLE 4: BRIDGE WATCH ALERTS

Date	Location	When Triggered	Amount (in)	Time Frame	Actual Rainfall (in)
11 Sep	*Buchanan*	*3:09 AM*	*0.25*	*1 hr*	*0.14*
11 Sep	*Bremer*	*2:51 AM*	*0.25*	*1 hr*	*0.06*
11 Sep	*Polk*	*1:57 AM*	*0.25*	*1 hr*	*0 **
17 Sep	*Polk*	*6:16 AM*	*0.25*	*12 hrs*	*0.40**

* indicates precipitation summaries from NOAA.gov

TABLE 5: RAINWAVE ALERTS

Date	Location	When Triggered	Amount (in)	Time Frame	Actual Rainfall (in)
1 Sep	*Polk*	*5:05 AM*	*0.25*	*24 hrs*	*0 **
11 Sep	*Bremer*	*3:10 AM*	*0.25*	*24 hrs*	*0.06*
11 Sep	*Bremer*	*5:05 AM*	*0.25*	*24 hrs*	*0.74*
17 Sep	*Bremer*	*12:50 PM*	*0.25*	*24 hrs*	*0.23*

* indicates precipitation summaries from NOAA.gov

TABLE 6: RAINWAVE MONTHLY EVENT SUMMARY FOR BREMER

Date	Amount (in)	Actual Rainfall (in)	Alerts Recieved
11 Sep	*1.12*	*0.06*	*YES*
15 Sep	*0.27*	*0.38*	*NO*
19 Sep	*0.35*	*0.74*	*YES*
28 Sep	*0.27*	*0.23*	*YES*

The alerts were compared for both accuracy and speed of delivery. While the BridgeWatch system did trigger events more quickly than RainWave, the level of accuracy varied. BridgeWatch, as in its name, reports rainfall data from nearby bridges, not necessarily the project sites. As seen in Table 4, BridgeWatch alerts arrive as soon as the location has surpassed 0.25 inches whether it be in 1 hour or 12 hours. While the RainWave service had a longer delay on reporting, due to the 24-hour measurement cycle, the data delivered was based on the actual location of the project site, rather than nearby bridges equipped with the BridgeWatch system. Table 5 shows that RainWave alerts arrive if there has been 0.25 inches over a 24 hour period. Other weather data sources rely upon weather stations at local airports for atmospheric data. According to Wunderground.com and NOAA.gov, only 2 of the events in September 2013 would be classified as stormwater events (0.25 inches in a 24 hour period). The location of the data source is different from both BridgeWatch and RainWave, which affects the level of accuracy for reporting and alerting. If highly accurate rainfall data is required for a future project, either BridgeWatch or RainWave may provide the best options for triggered alerts for monitoring or site inspection.

SAMPLING SITES

The following information describes the sampling sites established for this project. The description includes physical characteristics, geographical location, and photo documentation of on-site conditions at different stages of the sampling season.

ANKENY

The Ankeny site resided in Polk County and included Otter Creek. The upstream location, AnkUp, flowed adjacent to agricultural land into a culvert under Highway 35. When there was flow upstream, it was usually covered in surface algae (Figure 6). As the season went on, the upstream location was overtaken by vegetation (Figure 7). As drought set in during September 2012 and 2013, the upstream location had no flow or surface water on site (Figure 8).

Figure 7 – AnkUp overtaken by vegetation, facing downstream

Figure 6 – Algae at AnkUp, facing upstream

Figure 8 – AnkUp in the September 2013 drought, facing downstream

ANKENY

The downstream location at Ankeny was surrounded by open land adjacent to a golf course. The rising stage sampler was installed at the border of the golf course (Figure 9). As seen in Figure 9, the fence was placed straight across the stream that separated the golf course. This created some debris buildup as the season went on. A unique feature of this site was that vegetation did not establish all the way to the waterline (Figure 10). At some point, riprap was put down as a channel and bank stabilization but became buried in sediment as the site flooded early in the season. This may be one of the reasons this site had such low water clarity and overall low water quality. During the drought in September 2012 and 2013, this location dried up almost completely (Figure 11).

Figure 9 – AnkDown rising stage sampler, facing downstream

Figure 10 – AnkDown facing the culvert, facing upstream

Figure 11 – AnkDown in the September 2013 drought, facing upstream

PRESSURE TRANSDUCERS

During the 2012 sampling season pressure transducers were installed at the Polk County sites (Figure 12) as a means of potentially assessing stream stage before, during and after storm events. The idea stemmed from other water monitoring projects conducted by the Principal Investigator. When properly deployed, pressure transducers can provide a clear indication of stream rise and fall in relation to storm events. Furthermore, when combined with flow and volume data, pressure transducers can help determine overall pollutant loads or reductions from a given site.

It was soon discovered during the project that runoff generated from the sampling sites contained too much sediment for the pressure transducers to properly work. While samples at the Ankeny site were collected from fixed rising stage samplers (an indicator of a rise in stream stage), the pressure transducers indicated no change in stream stage. This was primarily due to the fact that the device was buried in sediment and unable to properly function.

Figure 12 – Pressure transducers buried in mud at the Ankeny sampling site

Pressure transducers are used to measure stream stage by correlating atmospheric pressure with the pressure generated from surface water above a device installed in a stilling well. Proprietary software is used to convert raw data to stream level measurements over a time series specified by the user. Nearly all data collected from pressure transducers used as part of this study was corrupted. Heavy sediment loads contained in the water bodies, combined in several instances with little to no flow, caused pressure transducers to function improperly. The image included in this report is from the Ankeny site, where pressure transducers installed on site were buried in sediment. All data recorded was zero.

Pressure transducers were not deployed during the 2013 sampling season.

BUCHANAN

The Buchanan site resided in Buchanan County and included Bear Creek. The upstream sampling point was immediately upstream to bridge construction on Highway 150 (Figures 13 & 14). This site was unique in that one bank was reinforced with riprap and the other was mostly exposed soil (Figure 15). There was heavy rainfall in May and June but the upstream location was mostly unaffected.

Figure 13 – BuchUp near bridge construction

Figure 14 – BuchUp, facing upstream

Figure 15 – Exposed bank

BUCHANAN

The downstream sampling location was adjacent to a wooded area and moderately sized shed. As seen in Figure 16, the woods came very close to the waterline. Figure 17displays the stream meandering through the woods with a low, calm flow. This stretch of Bear Creek had a cobble bottom (Figure 18) and very high water quality throughout the season. Figures 19 and 20 show the results of heavy rainfall during June, where the stream jumped the bank downstream and starting flowing through the woods.

Figure 16 – BuchDown, facing upstream

Figure 17 – BuchDown, facing downstream

Figure 18 – BuchDown, cobble bottom

BUCHANAN

Figure 19 – BuchDown, June flooding the created flow through wooded area

Figure 20 – BuchDown, June flooding, facing upstream

WAVERLY

The Waverly site resided in Bremer County and included Quarter Section Creek. The upstream location is flanked by a reservoir and woods (Figure 21). During normal conditions there is standing water in the north (Figure 22) and south (Figure 23) ditches. Because of the steep slope, sampling usually happened with a sampling bucket off the top of the culvert (Figure 22). Heavy rainfall in June 2012 dramatically increased the water level to the point that the adjoining reservoir and stream merged (Figure 24).

Figure 21 – WavUp, upstream

Figure 22 – WavUp, north bank

Figure 23 – WavUp, south bank

WAVERLY

Downstream, Quarter Run meanders from the culvert to an agricultural area (Figure 25). The east bank was where samples were extracted, near the culvert (Figure 26). In the middle of the season, bank reconstruction started taking place (Figure 27) and was completed at the end of the season (Figure 28).

Figure 24 – WavUp, June flooding, north bank

Figure 25 – WavDown, facing downstream

Figure 26 – WavUp, facing downstream

Figure 27 – WavDown, bank reconstruction

Figure 28 – WavDown, completed bank reconstruction

WEST DES MOINES GRAND

The West Des Moines Grand site resided in Polk County near the Grand Ave. Exit of Interstate 35. The site included an unnamed stream that ran into the Raccoon River. The stream flowed from a wooded area, through rip-rap and under the highway culvert (Figures 29 & 30). On the border of where the wooded area met the rip-rap, a rising stage sampler was installed (Figure 29).

Figure 29 – WDMGUp, facing upstream

Figure 30 – WDMGDown, facing downstream

Figure 31 – WDMGDown, facing upstream

The downstream location runs from the culvert around a small bend and into Raccoon River. There is some rip-rap located at the discharge point of the culvert (Figure 31) but mostly silt and brush from the bend to the stream channel (Figure 32). The downstream passive sampler was installed in the bend.

Figure 32 – WDMGrand, downstream site

During the remaining site visits in September 2013, there was equipment upstream (Figure 33) with a rainbow sheen around it (Figure 34). The sheen was not biological.

Figure 33 – Upstream, equipment in the stream, September 2013

Figure 34 – Upstream, sheen in the stream, September 2013

WEST DES MOINES GRAND

At the downstream sampling location on the last sampling day in September 2013, there was a second stream that was flowing that had not been there previously. It was milky in nature and flowing directly into the downstream that was just yards from the Raccoon River. As seen in Figure 35, the stream near the rocks is fairly clear with the muddy bottom visible. Directly to the left of that is a milky substance mixing directly with the stream. A cause for the milky substance was not determined during the site visit.

Figure 35 – Downstream, milky discharge into stream, September 2013

At each site, assessments were performed both in the field and in the lab. Physical assessments in-field included weather conditions, water color, stream flow, water temperature, and clarity through transparency tube. Physical assessments in-field (Table 7) include streambed substrate identification, canopy cover percentage, riparian zone, adjacent land uses, and photographing. Chemical assessments in-field include pH, dissolved oxygen, nitrate-N/nitrite-N, and phosphorous. Lab analysis include turbidity, transparency with acrylic transparency tube, Total Solids Water, and Total Solids Soil.

TABLE 7: PHYSICAL SITE CHARACTERISTICS

County	Name	Vegetation Coverage (%)*				Streambed Material	Adjacent Land Use
		right	left	right	left		
Polk	*AnkUp*	*0*	*0*	*0*	*0*	*Muck*	*Crop*
Polk	*AnkDown*	*75*	*75*	*0*	*0*	*Muck*	*Golf Course*
Buchanan	*BuchUp*	*0*	*25*	*0*	*0*	*Sand & Muck*	*Crop*
Buchanan	*BuchDown*	*100*	*100*	*25*	*0*	*Cobble*	*Crop*
Bremer	*WavUp*	*100*	*100*	*0*	*0*	*Sand*	*Woods*
Bremer	*WavDown*	*0*	*0*	*0*	*0*	*Sand*	*Woods*
Polk *Polk*	*WDMGUp*	*0*	*0*	*0*	*0*	*Muck & Riprap*	*Crop*

* “Right” and “left” indicate readings taken by facing upstream and describing the conditions directly right and left of the sampling location

OBJECTIVES

Grab samples were taken twice a month at each location and after stormwater events. Because runoff is a concern of highway construction sites, our sampling frequency was chosen to most accurately reflect water quality in response to rainfall. Stormwater events are defined as storms producing 0.25 inches of rain over 24 hours. During the 2013 sampling season, there were 31 scheduled events and 30 stormwater, or triggered, events. This allowed a healthy ratio of about half “normal” samples and half “stormwater runoff” samples.

The primary hypothesis was the acrylic transparency tube (Figure 36) is an appropriate, cost-effective way to test basic water clarity when compared to a turbidimeter. While other methods may garner a higher level of accuracy, for the sake of rapid, basic data collection and response, the transparency tube provides reliable, simple methods for gathering information. This can allow for quicker decision making and actions to protect the resources potentially impacted by construction site discharges.

Transparency is the ability for water to transmit light and can be analyzed by how well a symbol is seen, or reflected, at the bottom of a transparency tube (Figure 37). The tube is filled with the water to be analyzed and then slowly released via a drain tube at the bottom. The viewer looks directly down the tube until the symbol becomes visible. The drain tube is then crimped off and the reading is taken of the water level remaining in centimeters. The lower the reading, the more “dirty” the water is (Water Monitoring Equipment and Supply).

Figure 36 – Acrylic transparency tube

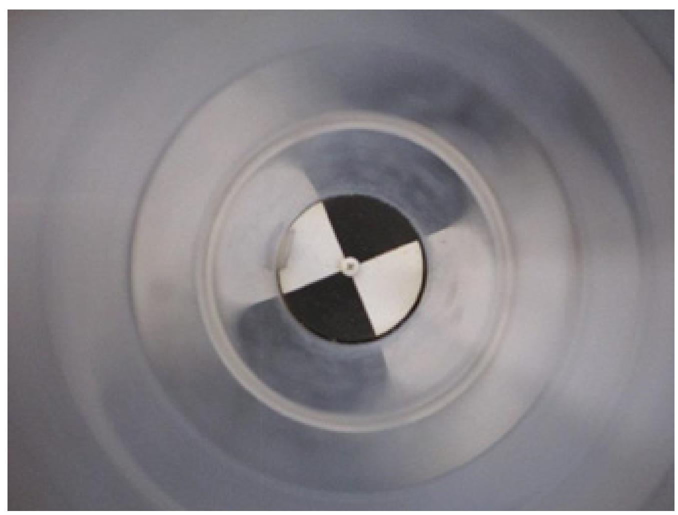

Figure 37 – Image at the bottom of transparency tube

OBJECTIVES

The same principle was applied when comparing our transparency tube readings at construction sites to those done by a turbidimeter. Ideally, the transparency tube readings will always be done in the field by trained personnel. Readings were taken from both the field (one reading) and in the lab (three readings) for quality assurance. Two to three people were responsible for reading the transparency tube to assure that eyesight and height were of no consequence. The tube chosen could accurately read for transparency between 5 cm (highly turbid/"dirty" water) and 60 cm (very clear).

Turbidity is the "cloudiness" of water and is analyzed digitally by how a light beam is refracted through the water. The more particles within the water, the more light is scattered leading to a more "dirty" water sample (Water Monitoring Equipment and Supply). Using a digital turbidimeter is generally considered the standard when measuring water quality in the field. The turbidimeter used was a portable HACH 2100Q and was chosen because of its accuracy and ease of use (Figure 38). Quality control for this instrument included calibrations done with formazin solution before every use and by repeating the sample reading twice.

Total Solids Soil is a standard analysis used to find the soil moisture percent. According to Minet, Laloy, Lambot, and Vanclooster (2011), soil moisture prior to rainfall is a key factor in determining the runoff due to its effects on infiltration capacities. Soils that are poorly permeable, or during high intensity rainfalls, yield an unpredictable runoff response. Soil moisture data from our sites were compared to field transparency, lab transparency, and turbidity to see if there was a correlation between soil moisture caused from runoff and sediment concentration within the adjacent stream. Figure 39 previews one aspect of the desiccation process for Total Solids soil analysis.

Figure 38 – Hach 2100Q turbidimeter

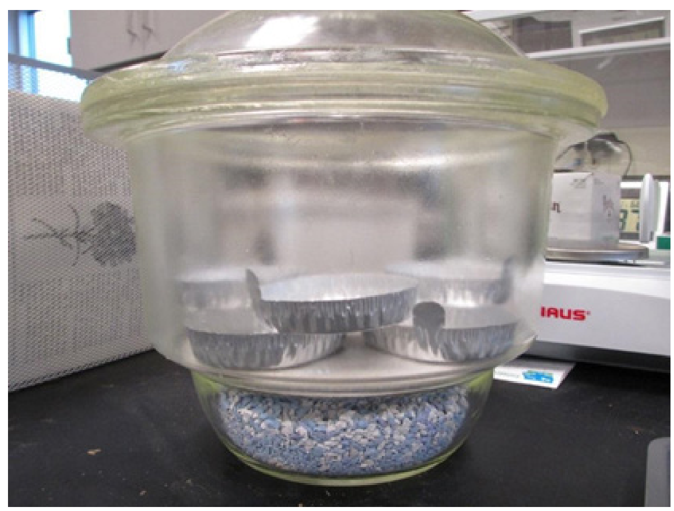

Figure 39 – Desiccator containing Total Solids soil samples

OBJECTIVES

Total Solids Water is a standard analysis used to find sediment concentration within a water sample. In order to find the dry mass of sediment within a sample, either filtration or evaporation is used. Filtration is costly and complicated so evaporation was used (Julien, 2010). The analysis was compared to field transparency, lab transparency, and turbidity to see if there was a correlation between dried sediment concentration and suspended sediment concentration.

Total Solids analysis is performed by evaporation using a combination of weighing, baking, and desiccating (drying). An initial weight is taken of the dish and sample then is baked overnight. The sample is then placed in a desiccator for an hour and then weighed. This processes is repeated until the recorded weights are between +/- 0.005g. The percent moisture is calculated by how much weight was lost between the initial and final weigh back.

Settlable Solids are a useful tool when samples are highly turbid. In our turbidimeter, samples containing over 1000 NTU's are not readable. If the samples are diluted,they may become a non-representative sub-samples. Another problem with just relying on the turbidimeter is that because smaller particles scatter light more uniformly, larger particles can be a problem. In many of our highly turbid samples, there are large debris particles. Water color and temperature, which also varies widely per sample, also has an effect on a turbidimeter. In the acrylic transparency tube, samples that are less than 5 cm are not readable. Both particle size and water color affect the reliability of the acrylic transparency tube (Pavanelli & Bigi, 2005). Therefore, it is reasonable to use the Settlable Solids test on samples that are highly turbid. Furthermore, the relation of Settlable Solid Concentration and turbidity can be used exchangeably (Bayram, Kankal, & Hizir, 2011).

A Settlable Solids is performed with 1 L of a water sample and an Imhoff cone set. The sample is inverted and poured off into a cone; then wait for 1 hour (Figure 40). Record the amount of settled solid in the cone in mL. Stir the sample and wait 24 hours. Record the final amount of settled solid in the cone. This method has been researched thoroughly and has a high degree of reliability (99%) when compared to standard lab samples using silica as a solid in filtered stream water (Pavanelli & Bigi, 2005). Overall, Settlable Solids is a simple, cost competitive, and reliable.

Figure 40 – Settable Solid analysis

Figure 40 represents the methods for measuring settleable solids in water. Varied concentrations of sediment in water are allowed to settle over time. As material settles, both time and depth are measured and compared. Full explanation of settleable solids is available in the standard operating procedure (SOP) developed as part of this project.

SAMPLE ORGANIZATION

Discrete (Grab) Samples for Scheduled Sampling/Dry Weather Events Only

Scheduled sampling occurred every two weeks at the project sites. These samples were taken during "dry weather," or at scheduled events versus events triggered as a result of a storm event. Table 8 is a summary of the discrete (grab) samples taken in the field and the number of samples tested in the lab. There was a total of n=125 samples taken from the field and n=120 samples tested. Five samples were not tested due to three conditions:

1. Samples were taken once at the wrong location at AnkUp and AnkDown.
2. Sample bottles broke on one occasion for BuchUp and BuchDown.
3. A sample from WavDown was not tested in the lab.

TABLE 8: DRY WEATHER FIELD SAMPLES & SAMPLES TESTED

Location	Total Field Samples	Total Samples Tested
AnkUp	10	9
AnkDown	10	9
BuchUp	19	18
BuchDown	20	19
WavUp	22	22
WavDown	21	20
WDMGUp	11	11
WDMGDown	12	12
Total (n) =	125	120

SAMPLE ORGANIZATION

Protocols for discrete samples were based on the IOWATER volunteer water monitoring program, which also incorporates discrete sampling techniques implemented by the Iowa DNR Ambient (professional) Water Monitoring Program.

Composite, passive samples were also taken from the study sites within 24 hours of storm events. Rising stage samplers were used for passive sampling during triggered storm events. No rising stage samples were taken during dry weather or “scheduled sampling.” A total of 23 rising stage samples were collected, with ten sets of sample data used for the study. The sampler stationed at the upstream location for Ankeny had little to no flow during one entire sampling season. Due to seasonal drought, there was also little or no stream flow at the two sites located in Ankeny (AnkUp and AnkDown) during most of the 2013 sampling season. Other samples were not tested due to holding time restrictions. Sample collection constraints included inability to reach the site within a 24-hour period, whether due to staffing availability or high water. As a result, 13 samples exceeded a 24-hour holding time for sample analysis (Table 9).

If use of rising stage samplers were to be repeated, a recommendation would be to have a local contact collect samples for triggered events. As seen in Table 9, 23 samples were collected from the sites but only 10 were tested, resulting in only 43% of the total samples collected within the 24-hour holding time requirement. The project sites were located, in most cases, hours away from the lab headquarters and travel was not always possible due to staff availability.

TABLE 9: TRIGGERED/RISING STAGE TAKEN & SAMPLES TESTED

Location	Rising Stage Samples	Samples Tested
AnkUp	4	0
AnkDown	4	2
WDMGUp	6	3
WDMGDown	9	5
Total (n) =	23	10

SAMPLE ORGANIZATION

The rising stage samplers were also subject to the unique conditions for each project site. Some sites had flowing water, whereas others had slow or stagnant flow. Calibration for sample collection was also highly subject to existing water levels at the time of the site visit. Many streams fluctuate water level dramatically depending on stream width, depth, and rainfall (Julien, P.Y., 2010). It is difficult to gauge where to place the bottles according to a “normal” stream level when each stream is unique at any given point in time. Some were placed higher than the water level. As the stream rose during some storm events, the stage never rose high enough to fill the bottle during at least four storm events. Estimating rainfall amounts could account for adjustments to the bottle placement, but would also require a local resource to assist with such modifications due to the distance to project sites. Lack of rainfall between some sampling events also meant stream stage levels would fall, rendering the sample bottles too high to fill if a 0.25 inch rain event were to occur (Figure 41). Overall, using rising stage samplers to collect the first flow of a rising stream does work well for cost-effective, passive sample collection. However, those collecting the samples should observe the conditions closely, and by a local contact, as water flow and stage levels can change dramatically depending on weather activity. Should a higher level of accuracy or precision be required for sample collection, equipment such as a Teledyne ISCO™ automated sampler may be used.

Figure 41– Rising stage sample bottles at AnkUp were set at the given water level at the time of the site visit. After one week with no rainfall, the stream stage dropped dramatically.

RATIONALE FOR USING RISING STAGE SAMPLERS

The Nalgene rising stage samplers were chosen for implementation due to the low cost of initial deployment. However, because the tools are highly subjective based on site conditions and water flow, sample data was not as accurate or precise as it may have been with a more sophisticated sampling system. With a high degree of accuracy and precision, use of ISCO samplers also come at a high price and a high degree of required calibration. The objective of the project was to identify cost-effective means of gathering information at the highest possible level of accuracy. Unfortunately, the sample collection system was not as precise or accurate as systems where automated sampling equipment is used. However, the cost comparison reflects a 48 to one difference in expenses. For programs seeking rapid, inexpensive means of gathering basic information, the rising stage sampler method may be appropriate.

Figure 42: Teledyne ISCO automated sampler with composite water samples following a triggered storm event. With a high degree of accuracy and precision, use of ISCO samplers also come at a high price and a high degree of required calibration.

CHAPTER 5

ANALYTICAL TEST RESULTS

Water and soil tests were performed both in the field and in the lab as part of this study. Tests performed include field-based transparency tube readings, lab-based transparency tube readings, lab-based turbidity, lab-based Total Solids soil, lab-based Total Solids water, and lab-based Settable Solids. Turbidity measurements for all samples taken served as the control for all other tests conducted. Below are the results for: lab transparency compared to turbidity, field transparency versus lab transparency and field transparency compared to turbidity. It was concluded that transparency is just as reliable as turbidity for assessing sediment concentrations in surface water. Results of these comparisons are shown in Figures 43 through 48, respectively. The following analyses were also compared to lab transparency readings: Total Solids soil, Total Solids water. The final data set includes a summary of all results compiled as part of this study.

Lab Transparency v Turbidity

With a total of n = 104 averaged samples, a power trendline (a type of linear regression found in Microsoft Excel) was created with r2 of 0.91 out of 1.0. The polynomial equation for this analysis was y = 217x-0.648.

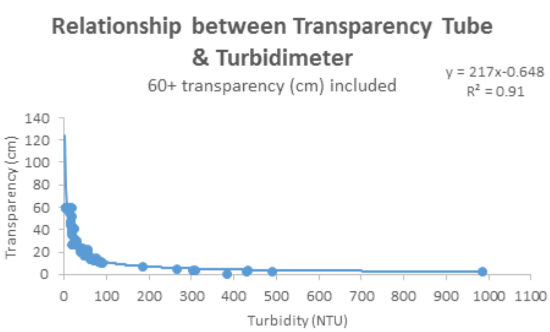

Figure 43 – Relationship between the lab transparency and turbidity measurements

Because the transparency tube does not accurately read over 60 cm, all results greater than 60 on the y-axis were removed and another graph created. For this graph, n = 50 and r2 = 0.98 (confidence) and the equation was y = 342.09x-0.748.

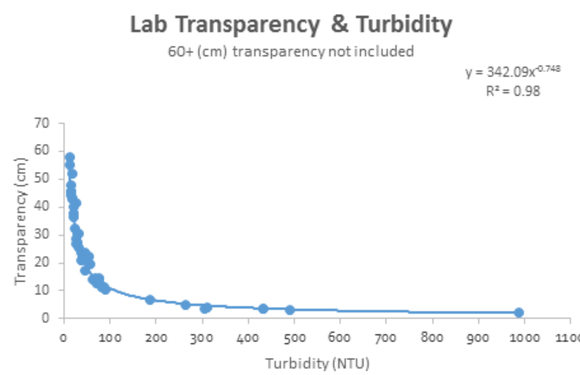

Figure 44 – Relationship between lab transparency and turbidity measurements

Field Transparency v Lab Transparency

With a total of n = 103 averaged samples, a power trendline was created with an r2 of 0.79 and equation of y = 1.3044x0.9244.

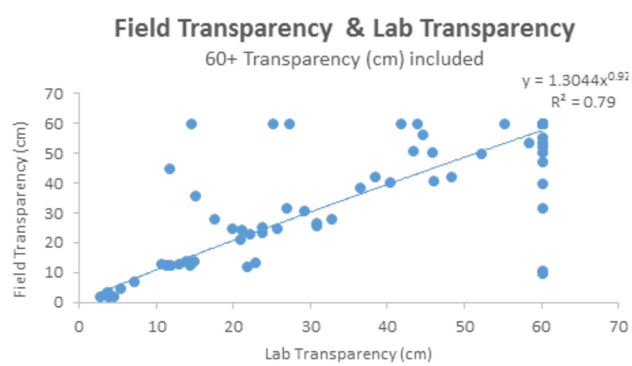

Figure 45 – Relationship between the lab transparency and turbidity measurements

Because the transparency tube does not accurately read over 60 cm, all results greater than 60 on both the x and y-axis were removed and another graph created. For this graph n = 45 and r2 = 0.87 and the equation was y = 0.9846x1.0167.

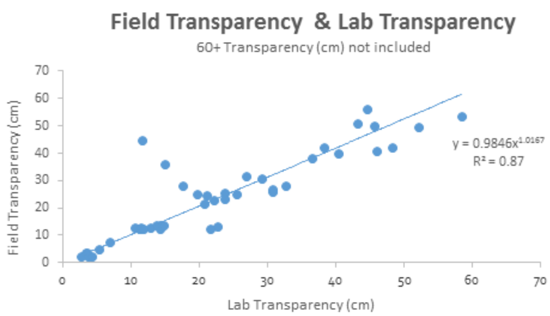

Figure 46 – Relationship between the lab transparency and turbidity measurements

Field Transparency v Turbidity — All sites

Turbidity measurements were only conducted in the lab. Both field-based transparency and lab-based transparency measurements were compared with Turbidity measurements taken with two Hach turbidimeters: a Hach 2100P and 2011Q models were calibrated upon each use. Results from both tests were included as a comparison of meter outputs as well as to compare with transparency data. Both meters generated consistent results throughout the project period. Here, n = 104 and r2 = 0.71 with an equation of y = 164.1x-0.547.

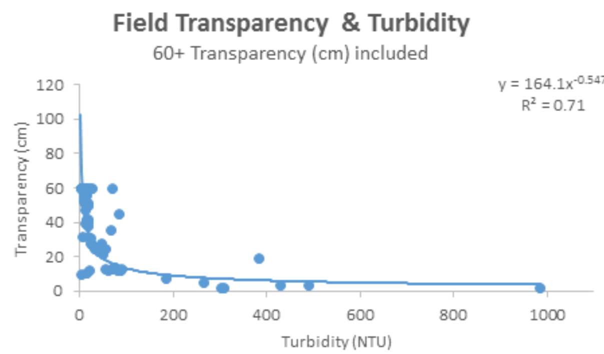

Figure 47 – Relationship between the lab transparency and turbidity measurements

When values greater than 60cm for transparency data were excluded, n = 55, r2 = 0.63, and the equation was y = 156.11x-0.557.

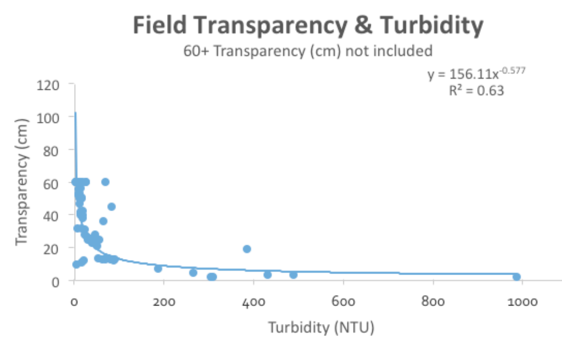

Figure 48 – Relationship between the lab transparency and turbidity measurements

SCHEDULED VS. TRIGGERED SAMPLE DATA

Sample data from scheduled events was compared to triggered storm events as a means of determining correlation between transparency and turbidity measurements for both sample types. A total of 125 samples were collected from field sites over the course of two construction seasons in 2012 and 2013, as shown in Table 10. Of all samples collected, 120 were tested both in the lab and in the field for transparency and turbidity. The majority of samples tested were from triggered events, and samples collected from the Buchanan County site and Waverly site. Samples not tested were due to holding time constraints and also, in two instances, bottles being inadvertently dropped, thus contaminating the samples.

TABLE 10: SUMMARY OF SAMPLE DATA

TABLE 10: SUMMARY OF SAMPLE DATA

Field Samples v Samples Tested

Location	Total Field Samples	Total Samples Tested	Scheduled	Triggerec
AnkUp	10	9	8	2
AnkDown	10	9	8	2
BuchUp	19	18	6	13
BuchDown	20	19	7	13
WavUp	22	22	8	14
WavDown	21	20	7	14
WDMGUp	11	11	7	4
WDMGDown	12	12	7	5
Total (n) =	**125**	**120**		

Analysis for both scheduled and triggered storm events were included in the testing data. A linear regression model was used to determine the percentage of correlation to be explained by the regression line. In both instances, scheduled and triggered events, the regression analysis proved a strong, positive relationship between transparency measurements and turbidity as a means of assessing concentration of sediment in surface water.

Due to the time constraint for collecting samples, it was necessary to divide collection times based on geography. Scheduled sample collection occurred on a bi-weekly basis, with "North" sites consisting of the Waverly/63 and Buchanan/150 locations, and "South" sites including Ankeny and West Des Moines-Grand. Samples were collected every other week from sites as a means of amassing a dataset for "dry weather" sampling. As a result of no storm event triggering the sampling activity, most values recorded were assumed to be both low in NTU value and high for transparency measurements. These samples are primarily intended to characterize "normal conditions" in the water body for a given site.

The regression line for the comparison of transparency to turbidity, shown in Figure 49, skews to the left as a result of the low NTU/high transparency tendency for sample measurements. The r2 value of 82.26 indicates a relatively strong relationship between the two measurements.

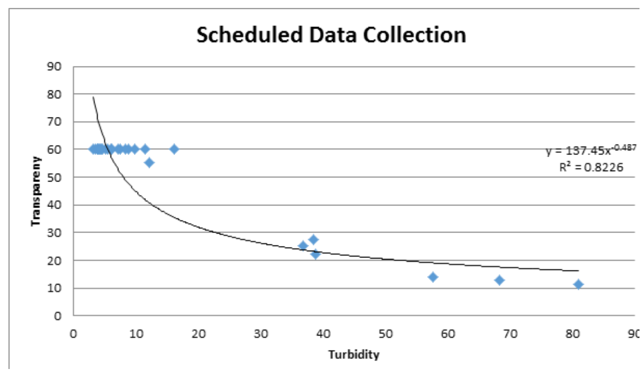

Figure 49 – Comparison of transparency to turbidity measurements for scheduled data collection

Triggered Sample Data: Transparency compared to Turbidity

A .25 inch rainfall within a 24 hour period triggered event-based sampling activity. If scheduled sampling was intended for a given day of triggered events, data was considered for a triggered event only. The purpose of sampling at this time was to characterize water quality impacts from both the storm event and potential land disturbance or soil loss activities occurring within the DOT construction site. Initial storm alarms were triggers for sampling. If storm events occurred in sequence, over the course of several days, only the initial alarm served as the trigger for sampling, with scheduled sampling continuing the following week to both remain on schedule and also determine stream conditions upon "recovery" from recent storm events.

The data contained within the triggered dataset more closely represents the correlation between transparency and turbidity for sample data. While values continue to skew left, the distribution does indicate a strong linear correlation between transparency and turbidity datasets for storm-triggered sampled. Because scheduled sampling did not occur during storm events, scheduled samples had higher water clarity. Furthermore, the r2 value for the regression line, shown in Figure 50, explains 96.7 percent of the correlation between the two measurements. With such a high r2 value, one can consider transparency data a strong surrogate for turbidity data when analyzing sample data from triggered storm events.

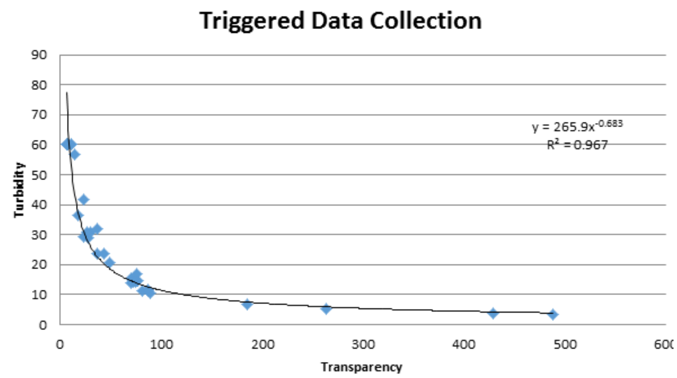

Fig. 50: Correlation of triggered data for transparency and turbidity - all samples

Field Transparency v Lab Transparency

When comparing field-based transparency measurements to lab-based transparency measurements, data from triggered sampling events indicate a stronger relationship between transparency and turbidity – both for sample sets including transparency measurements over 60 centimeters and the data set without. The disparity for scheduled sampling comparisons may correspond to the need to re-suspend samples and organic material degradation as samples are stored in the lab cooler. Figure 51 shows a weaker relationship between field-based transparency measurements taken and those taken after samples were delivered to the lab. However, the r value of .86, shown in Figure 52, indicates sediment-laden water collected from storm events may result in a stronger relationship between sample data collected in the field versus tests run in the lab. When removing values greater than 60 centimeters, the r value for triggered events jumps to a 97 percent confidence level.

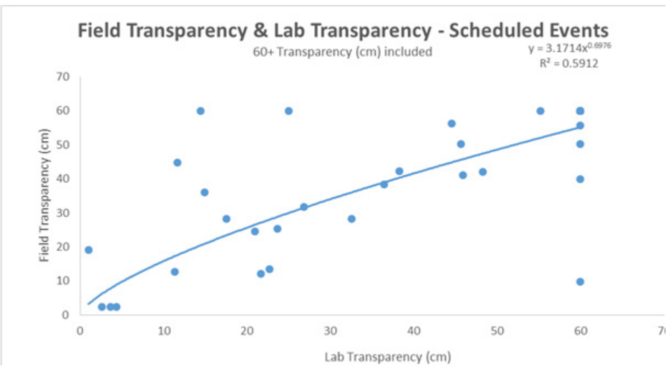

Fig. 51: Field Transparency vs Lab Transparency - for scheduled events, 60+ cm included. $r^2 = .5912$

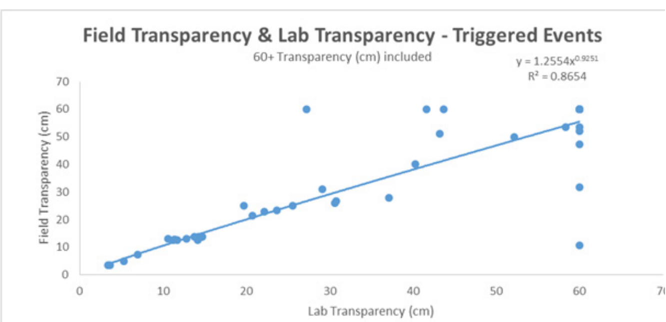

Fig.52 : Field Transparency vs Lab Transparency for triggered events - 60 cm included. $r^2 = .8654$

Because transparency tubes used for the project only measure 60 centimeters of water depth, results of 60 cm or greater tend to skew the regression line. Measurements at 60 cm and over for transparency were removed from the data set to better characterize the relationship between transparency and turbidity for samples of water containing sediment, versus relatively "clear" water, as shown in Figures 53 and 54.

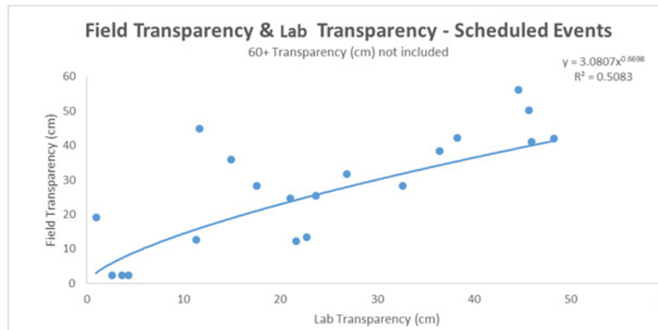

Fig. 53: Field Transparency vs Lab Transparency for Scheduled events - 60 cm excluded. $r^2 = .5083$

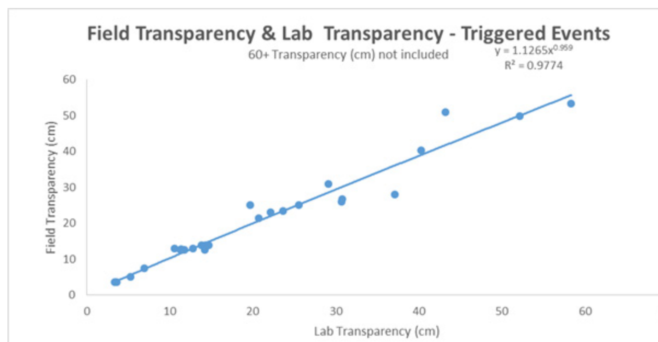

Fig. 54 : Field Transparency vs Lab Transparency for Triggered events - 60 cm excluded. $r^2 = .9774$

With an r2 factor of .95 and .98, there is a high degree of confidence that transparency measurements can be used as a surrogate for turbidity measurements when gathering water quality data from active construction sites. Should a higher level of precision or accuracy be required, or should regulatory compliance require such measurements, then a turbidity measurement may be the datum of choice. Until such requirements exist, the transparency tube may suffice as a basic surrogate for water quality data.

Transparency and Turbidity Data by Site

Transparency and Turbidity Data by Site.

With a total of 120 samples tested out of 125 collected, 58 were considered “scheduled,” while 67 samples tested were as a result of “triggered” events. The percentage-based difference is approximately 48:52, which results in nearly an even divide of sample data. When comparing results by site, both turbidity and transparency measurements for all sites follow a general, inverse pattern. Overall, turbidity measurements remained within a general limit of 200 NTU. Triggered sampling from storm events did generate outlying values greater than 1,000 NTU for downstream samples at West Des Moines-Grand and Ankeny. Upstream samples at Ankeny also had high NTU values due to agricultural runoff.

For all sites sampled, both lab and field transparency measurements remain relatively consistent. Between all the sites, the turbidity readings had a standard deviation of 85.84, lab transparency at 3.40, and field transparency at 1.61.

Lab and field-based transparency testing did contain mild variation. Differences in data may be explained by the concentration of suspended material during field testing versus the need to re-suspend material for lab-based testing. Organic material may also have been lost by adhering to sample bottles, or general decomposition.

Lab-based transparency measurements tend to indicate a reduced standard error value for all sites. This may be due to fewer extraneous factors within the indoor testing environment, consistent lighting, and other more constant factors unavailable in an outdoor data collection environment. Conversely, sites where a greater volume of data were collected indicate a broader midrange of measurements. This includes the Waverly and Ankeny sites in particular, as both sites incurred more sample collection 2012 and 2013 seasons.

Anecdotal Site Information

The following details describe conditions during the 2012 and 2013 sampling season, as recorded by individuals involved with sample collection.

For all sites, no rain occurred from Memorial Day to Labor Day in 2012. As a result, only scheduled sampling occurred.

Ankeny. Over the 2013 season, water became overrun with algae, scummy, scaly, and smelly. At the end of September banks were seeded but there was no flow. The downstream site had muddy stagnant water, because by August, there was little to no flow.

Ankeny. There is not a clearly defined relationship between storm events (precipitation in a given area) and the concentration of sediment in samples collected for upstream and downstream sites. Ankeny had essentially no rain anytime around September 8th, yet sediment concentrations were high. This may have been from a storm occurring North of Ankeny or there could be another cause. Other factors than sediment can also influence turbidity levels. In July, there were algae blooms downstream and dark brown water upstream.

At AnkUp, banks were unstable. There were several inches of mud over the rip rap downstream. Over the season, water became overrun with algae and remained stagnant. By late September, banks were seeded but there was no flow. Reed canary grass also reduced upstream flow.

While physical samples were not necessarily the true indicators of water quality conditions, observations made on-site during these visits help characterize conditions within the stream and relate it to activities underway on the construction site. Impacts to water resources can be detected by more than just water sampling and testing. Physical site observations such as these can also help clarify unclear results generated from testing, as well as explain phenomena that may not be expected in basic test results.

Buchanan. For the Buchanan site, both upstream and downstream sites were very similar. On May 30th a significant spike in turbidity was recorded. According to Wunderground.com, Buchanan received 0.49 inches of rainfall that day with only 0.02 inches the day before.

By June 5th, flooding was down but water flow was still relatively fast. The concentration level dropped on June 13th when straw was applied on the shore that cut back due to active erosion. There was a slight increase in turbidity levels in mid-July due to high rain. Additional erosion and sediment control practices were applied to the site following the storm event.

For 2013, both upstream and downstream Buchanan sites were very similar. On May 30, high turbidity concentrations were recorded. According to Wunderground.com, Buchanan received 0.51 inches of rain within a 24-hour period. Data sheets indicate massive flooding the same day. The downstream sampling site was flooded as a result of ongoing rainfall.

By June 5, flooding was down but water flow was still relatively fast. Straw wattles and other erosion control practices were installed on site in June. There was a slight spike in turbidity later in mid-July due to heavy rain.

Waverly. At the Waverly site, both the upstream and downstream locations were very similar. On May 29, Waverly received 2.81 inches, and on June 25, Waverly received 0.43 inches of rainfall. According to date sheet, there was massive flooding On May 30.

From July 1 to the end of the season there was a drop in turbidity.

West Des Moines Grand. June and July had low water levels and little to no flow. The trend in August was high flow with normal water levels. September had higher rainfall.

Total Solids Soil v Transparency

Total Solids was selected as a testing method for both soil and water due to the relatively low input costs for data. Methods are based on EPA standard testing protocols. Soil samples were collected from locations with exposed soil adjacent to water monitoring sites. When comparing the cost of a turbidimeter at approximately $1,200.00, equipment necessary for total solids analysis was approximately 60 percent of the cost. Materials used included a glass dessicator, granular dessicant, and porcelean crucibles. The laboratory used for this analysis was already equipped with a calibrated scale and two drying ovens, which rapidly expedited the drying process. However, for cost-saving purposes, the same analysis can occur by air drying each sample. This method does take a significantly longer period of time, making it less likely an effective method of collecting data for stormwater management purposes. Lab transparency measurements were used as the control for sediment concentration. These measurements were compared to the traditional Total Solids Soil test to analyze a possible relationship between soil moisture and sediment concentration. As seen in Figure 56, n = 104 and r2 = <0.01 which shows no correlation between the two variants. The equation computed, y = 74.847x0.0118, was neither accurate nor

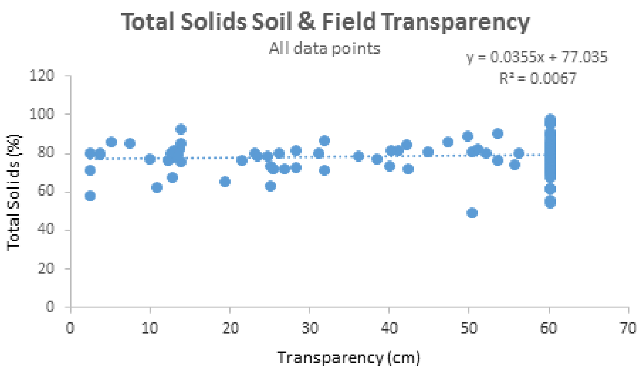

Figure 56 – Relationship between total solids and transparency measurements.

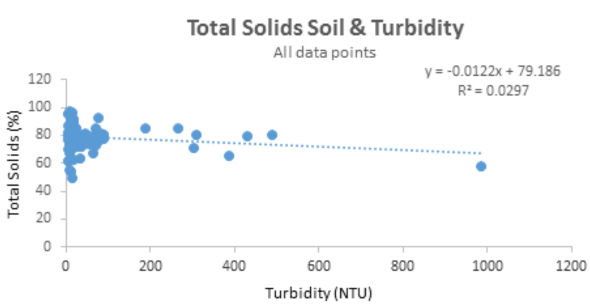

Figure 57 – Relationship between total solids soil and field turbidity measurements.

precise (Haby). Therefore, the relationship between soil moisture and sediment concentration was inconclusive for these samples.

Total Solids Soil v Field Transparency

The recommendation from this project is to utilize acrylic transparency tubes for field sampling and data collection. As a result field transparency measurements were compared with a more traditional test, Total Solids Soil. In this case, n = 104 and r2 = <0.01 which shows no correlation between the two variants. The equation computed, y = 0.0355x + 77.035, was neither accurate nor precise (Haby). Any relationship between the covariants proved inconclusive.

Total Solids Soil v Turbidity

Because turbidity served as the control and standard for sediment concentration, the methods were compared to the Total Solids Soil test. As with Figure 57, n = 104 and r2 = 0.03, which, again, shows no relationship between turbidity and soil moisture. As with field transparency and Total Solids, the equation computed, y = -0.0122x + 79.186, is neither accurate nor precise (Haby).

Total Solids Water

Out of 96 analyses, it was concluded that the method only yields trace amounts of sediment, which did not help us answer our initial question. The analysis was accurate but not precise (Haby), so we did not continue beyond 90 days from initiation.

TABLE 11: RESULTS SUMMARY

Test	Parameters	Total Numbers (n)	Confidence (r2) out of 1.0	Polynomial Equation
Lab Transparency v Turbidity	*All points* *Excludes those with 60 cm or more*	*104* *50*	*0.91* *0.98*	*y = 217x-0.648* *y = 342.09x-0.748*
Lab v Field Transparency	*All points* *Excludes those with 60 cm or more*	*103* *45*	*0.79* *0.86*	*y =1.3044x0.9244* *y = 0.9846x1.0167*
Turbidity v Field Transparency	*All Points* *Excludes those with 60 cm or more*	*104* *55*	*0.71* *0.63*	*y = 164.1x-0.547* *y = 156.11x-0.557*
Total Solids Soil v Lab Transparency	*All points*	*104*	*< 0.01*	*y = 74.847x0.0118*
Total Solids Soil v Field Transparency	*All points*	*104*	*< 0.01*	*y = 0.0355x + 77.035*
Total Solids Soil v Turbidity	*All Points*	*104*	*0.03*	*y = -0.0122x + 79.186*
Total Solids Water	*All points*	*96*	*N/A*	*N/A*

SETTABLE SOLIDS

For Settable Solids analysis, soil samples were first divided by horizon (A, B, or C) and then amount used (1 gram, 5 gram, 10 gram, or 15 gram). The samples were then labelled according to their horizon-amount (A-1 is horizon A and 1 gram of soil). The table below displays the average grams in each sample in 1 liter of water. Because we artificially created the concentration of soil in the water samples, a low standard deviation among samples was key for precise testing.

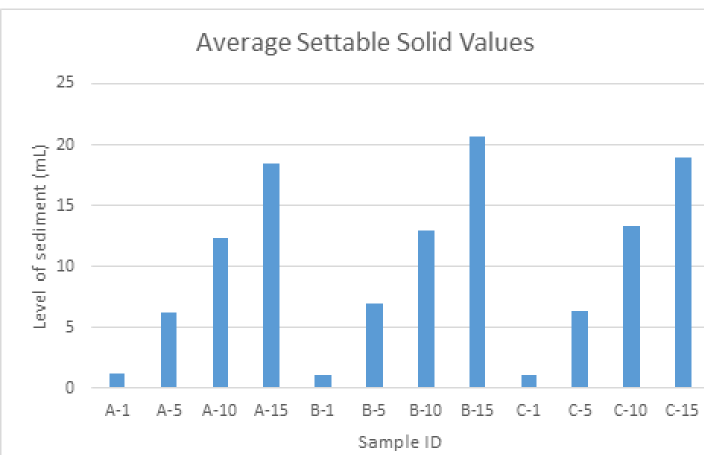

Figure 58 – Average settable solid Values for each soil horizon

As reflected in the results of Settable Solids analysis, there is little variation among the different soil horizons. When looking at the averages of each category, the standard deviation was less than 1 for the final settled level. The horizons with 15g of soil initially were closer to 1. This may be due to particle size or substrate among each horizon.
The weak relationship between settleable solids and transparency may be attributed to particle density and distribution. Smaller, clay particles disperse more evenly when suspended in water, but may settle more densely when water remains still for more than a 24-hour period. Because of this disparity, as well as the time constraint for proper analysis, this method is also not recommended for rapid data collection and analysis for stormwater management purposes, particularly on active construction sites.

Settable Solid Samples

Sample ID (Horizon-soil in g)	Average (g/L)	StD
A-1	1.07	0.01
A-5	5.04	0.02
A-10	10.04	0.02
A-15	15.07	0.02
B-1	1.06	0.01
B-5	5.05	0.02
B-10	10.16	0.18
B-15	15.03	0.01
C-1	1.06	0.03
C-5	5.07	0.02
C-10	10.04	0.03
C-15	15.07	0.02

Figure 59 – Created settable solid sample average concentration and standard deviation

The same samples were then run through transparency and turbidity analysis. The r^2, or strength of correlation between the two variables, was neither strong nor weak for transparency and strong for turbidity. This means that using the Settable Solids test for turbid samples is an accurate way to look at sediment concentration within water samples. One thing to note is that many of the samples between 10 and 15 g initially were below the readable limit for both transparency and turbidity. Settable

Solids testing is a simple, cost competitive, and reliable data. However, the results require up to 24 hours for proper analysis, which makes the test less than desirable for the rapid response necessary for response to storm-related water quality impacts.

By testing settleable solids, the objective was to determine whether or not soil horizon serves as a significant factor for transparency and turbidity testing. The initial project scope considered development of separate conversion charts based on soil horizons: A, B, or C. With r^2 values of .55 for transparency and .79 for turbidity, there is a moderate level of confidence that a single conversion chart may be used for comparing transparency and turbidity measurements, regardless of soil horizons sourced for sediment suspended in water.

Comparison to Transparency & Turbidity

Sample ID	Average mL	Average Cm	Average NTU
A-1	1.27	11.80	112.03
A-5	6.17	5.00	756.00
A-10	12.33	5.00	1000.00
A-15	18.50	5.00	1000.00
B-1	1.07	15.00	33.50
B-5	7.00	5.33	182.00
B-10	13.00	5.00	673.00
B-15	20.67	5.00	978.67
C-1	1.10	13.33	57.83
C-5	6.33	5.13	238.33
C-10	13.33	5.00	1000.00
C-15	19.00	5.00	1000.00
	r^2 =	0.55	0.79

Figure 60 – Comparison of transparency and turbidity values to settable solids

NUTRIENT DATA

Iowa DOT staff requested samples be collected and analyzed to determine nutrient concentration levels upstream and downstream of construction sites. The objective was to assess water quality conditions in relation to nutrient load impacts potentially sourced from DOT construction sites. Samples were collected at the Waverly and Ankeny sites during the summer of 2013. In both instances, concentrations of total nutrients, nitrates and phosphorus, were lower downstream from DOT sites than upstream. However, mean and median values of nutrient concentrations were relatively high, both upstream and downstream, in comparison to statewide averages. In both locations, agricultural runoff contributed significantly to upstream land conditions, and generated the highest concentration of overland flow to the adjacent water body.

In each instance, discrete (grab) samples were collected within the stream on site. Samples from overland flow on DOT sites would have required a v-notch weir or other method of concentrating flow for a calibrated sample. For the sake of general observation, the in-stream samples were collected as a more cost-effective means of initial data.

Data collection methods were based on the IOWATER volunteer water monitoring program. Equipment used consisted of Hach™ Nitrate/Nitrite test strips and Chemetrics™ total phosphorus test kits. Grab samples were also collected at each site and submitted to the State Hygienic Laboratory (SHL) of Iowa for analysis.

TABLE 12: ANKENY SAMPLE SITE NITRATE + NITRITE NITROGEN AS N

(Test strips measured as Nitrate/Nitrite, all in mg/L)

Date	Method	Upstream	Downstream	Method	Upstream	Downstream
4/30/2013	SHL	29	29	IOWATER		
5/24/2013	SHL	12	9.6	IOWATER		
5/31/2013	SHL	12	8.4	IOWATER		
6/25/2013*	SHL	23	22	IOWATER	20	20
7/11/2013	SHL	30	29	IOWATER	50	50
7/23/2013	SHL	22	22	IOWATER	20	20
7/25/2013	SHL	24	24	IOWATER	20	50
8/2/2013	SHL	19	14	IOWATER	20	20
8/8/2013	SHL	1.4	9.4	IOWATER	10	10
8/13/2013	SHL	4.2	1.9	IOWATER	2	
9/5/2013	SHL	0.1	0.1	IOWATER	0	0
9/23/2013**	SHL	0.1	0.1	IOWATER	20	20
	Mean	14.733333	14.125		0.3	0.3
	Median	15.5	11.8		20	20
	St. Dev.	11.256379	10.79782175		14.52584	17.67766953

***6/17/2013**	**Fertilizer Application**
****9/9/2013**	**Fertilizer Application**

Nitrate and nitrite are two forms of nitrogen. Nitrate is very easily dissolved in water and is more common in streams. Sources of nitrate include soil organic matter, animal wastes, decomposing plants, sewage, and fertilizers. Because nitrate is very soluble in water it can move readily into streams. Nitrite is another form of nitrogen that is rare because it is quickly converted to nitrate or returned back to the atmosphere as nitrogen gas. Due to its instability, detectable levels of nitrite in streams and lakes are uncommon (IOWATER, 2010). According to data collected by Iowa DNR from 2000 to 2009, the typical range for Nitrate + Nitrite-N in Iowa surface water bodies is 3 to 8.5 mg/L for rivers and streams, with seasonal fluctuation to as much as 20 to 50 mg/L during spring runoff events. The Iowa drinking water quality standard for nitrate concentration is 10 mg/L.

Both mean and median values of samples collected at both sites surpassed both the drinking water quality standard for nitrates (10 mg/L), and concentrations were more than double the typical range of 3 to 8.5 mg/L. While downstream nitrate levels were often lower than upstream values, overall the nitrate concentrations in both water bodies is well above what would be considered “normal conditions.” As a result, any land disturbance activities occurring on Iowa DOT sites should take precautions to avoid further contribution of nitrates to surface water adjacent to active construction sites.

TABLE 13: WAVERLY NITROGEN SAMPLE DATA

Waverly Sample Site

Nitrate + Nitrite Nitrogen as N

(Test strips measured as Nitrate/Nitrite, all in mg/L)

Date	Method	Upstream	Downstream	Method	Upstream	Downstream
3/21/2013	SHL	2.1	11			
4/10/2013	SHL	12	19	IOWATER	20	20
4/18/2013	SHL	18	19	IOWATER	20	20
5/24/2013	SHL	25	25			
5/28/2013	SHL	25	12			
5/30/2013	SHL	12	25			
6/5/2013	SHL	25	19			
6/13/2013	SHL	20	26	IOWATER	20	20
6/18/2013	SHL	25	14			
6/25/2013	SHL	16	24	IOWATER	10	5
6/26/2013	SHL	23	24	IOWATER	10	0
6/27/2013	SHL	24	25			
7/1/2013	SHL	25	22			
7/5/2013	SHL	22	2			
7/23/2013	SHL	2	12			
7/26/2013	SHL	1.8	0.1			
8/20/2013	SHL	0.1	0.27			
8/22/2013	SHL	0.38	0.21			
9/12/2013	SHL	0.26	0.1			
9/16/2013	SHL	0.1	11			
	Mean	13.937	14.534		0.3	0.3
	Median	17	16.5		13.38333	10.88333333
	St. Dev.	10.53586	9.666529013		15	12.5

TABLE 14: ANKENY PHOSPHORUS SAMPLE DATA

Ankeny Sample Site

Total Phosphorus as P

(Test kits measured as orthophoshate in mg/L)

Date	Method	Upstream	Downstream	Method	Upstream	Downstream
4/30/2013	SHL	0.05	0.05	IOWATER	N/D	N/D
5/24/2013	SHL	0.05	0.08	IOWATER	N/D	N/D
5/31/2013	SHL	0.10	0.1	IOWATER	N/D	N/D
6/25/2013*	SHL	0.25	0.3	IOWATER	E	E
7/11/2013	SHL	0.07	0.07	IOWATER	0.1	0.1
7/23/2013	SHL	0.14	0.2	IOWATER	0.6	0.6
7/25/2013	SHL	0.07	0.1	IOWATER	E	0.2
8/2/2013	SHL	0.08	4.1	IOWATER	N/D	N/D
8/8/2013	SHL	0.14	0.2	IOWATER	E	0
8/13/2013	SHL	0.09	3.6	IOWATER	N/D	N/D
9/5/2013	SHL	2.5	0.54	IOWATER	E	E
9/23/2013**	SHL	0.9	1	IOWATER	3	E
	Mean	0.37	0.861666667		0.3	0.3
	Median	0.095	0.2		0.6	0.15
	St. Dev.	0.710838	1.425602478		1.5502688	0.262995564

***6/17/2013**	**Fertilizer Application**
****9/9/2013**	**Fertilizer Application**

E = Testing error due to water too cloudy or green in color for proper testing procedures.
N/D = No Data

IOWATER tests strips were used to collect field-based data on nitrate and nitrite levels at sample sites. These values, when available, were compared to lab analysis. Unfortunately, only five sample sets within the twenty total field samples include IOWATER data, or one fifth of the total data set for the Waverly site. In addition, the test strips are often subject to the ability for the person taking the reading to interpret the color on the strip, and select the correct value, which ranges from: 0-2-5-10-20-50 and above. The test strips do not take fractions of measurements into account. Therefore, not enough data exists to make a clear comparison between the two testing methods. Such analysis may be considered for a future study as a means of establishing cost-effective methods for data collection. However, samples run at the State Hygienic Laboratory are currently priced at $16.00 per sample, which is one of the least expensive water quality tests requested of the lab. The test strips used for field data collection are approximately $40 per bottle, with 40 strips each, priced out to be approximately $1.00 per test. Nitrate concentrations in water tested during this project reflect conditions to be expected during typical seasons in Iowa. Springtime runoff tends to generate higher concentrations of nitrates in surface water, while levels tend to attenuate throughout the season. This is often due to the increase in vegetation during the growing season, as well as season application of fertilizers, which often occurs during the spring on agricultural land. According to Iowa DNR, background levels of nitrate and nitrite in Iowa are similar to what was recorded at the Ankeny project site. (IOWATER, 2010.)

Phosphorus levels in surface water were also analyzed as part of this project. Total phosphorus was analyzed by the State Hygienic Laboratory of Iowa, and Chemetrics phosphorus kits were used in the field. The test kits measure orthophosphate, which is the dissolved form of phosphorus.

According to data collected by Iowa DNR from 2000 to 2009, the typical range for total phosphorus in Iowa surface water bodies is 0.11 to 0.34 mg/L for rivers and streams, with a statewide average value of 0.2 mg/L for rivers and streams. Because algae growth is so highly responsive to phosphorus concentrations, even the smallest increase in levels can result in harmful algal blooms. With nearly all samples collected at the Ankeny site reflecting values above the statewide average of 0.2 mg/L, there may be potential water quality concerns. As values increase, the concentration grows exponentially, not numerically. Therefore, an increase in phosphorus levels from 0.9 to 1.0 is a greater order of magnitude than merely an increase by one unit. It may be recommended to Iowa DOT to consider reduced phosphorus or phosphorus-free fertilizers to reduce water quality impacts at construction sites.

Measurements taken after fertilizer applications indicate a significant increase in phosphorus concentration downstream. In particular, the downstream measurement taken on June 25 and September 23 were each preceded by a fertilizer application by Iowa DOT on the project site. No other samples taken from this site indicate a higher phosphorus level downstream from the project site than the upstream sample. Despite higher phosphorus levels downstream following fertilizer application, upstream phosphorus levels indicate sources other than Iowa DOT.

Phosphorus levels sampled from the Waverly site tend to remain closer or below the statewide average (.2 mg/L), however downstream sites tend to indicate a higher concentration. This may be due to the high volume of overland flow generated from both the DOT construction site and also adjacent land draining several miles of ditches upstream from the project site. It may be recommended to Iowa DOT to consider reducing or eliminating fertilizer applications containing phosphorus, particularly on sites with significant drainage from adjacent land (more than 80 acres) and roadside ditches over several miles.

TABLE 15: WAVERLY PHOSPHORUS SAMPLE DATA

Waverly Sample Site

Total Phosphorus as P

(Test kits measured as orthophosphate in mg/L)

Total Phosphorus - Waverly Site

Date	Method	Upstream	Downstream	Method	Upstream	Downstream
3/21/2013	SHL	0.36	0	IOWATER	0.2	
4/10/2013	SHL	0.44	0.46	IOWATER		
4/18/2013	SHL	0.34	0.38	IOWATER		
5/24/2013	SHL	0.09	0.09	IOWATER	0.1	0
5/28/2013	SHL	0.12	0.11	IOWATER	0.3	0.3
5/30/2013	SHL	0.78	0.85	IOWATER		
6/5/2013	SHL	0.14	0.14	IOWATER	0	0.1
6/13/2013	SHL	0.15	0.15	IOWATER	0.2	0.2
6/18/2013	SHL	0.05	0.06	IOWATER	0.1	0.1
6/25/2013	SHL	0.5	0.83	IOWATER		
6/26/2013	SHL	0.21	0.19	IOWATER	0.2	0.1
6/27/2013	SHL	0.16	0.17	IOWATER	0.1	0.1
7/1/2013	SHL	0.07	0.08	IOWATER	0.1	0.1
7/5/2013	SHL	0.05	0.05	IOWATER	0.1	0.1
7/23/2013	SHL	0.11	0.07	IOWATER	0.1	0.1
7/26/2013	SHL	1.7	0.08	IOWATER	0.1	0.1
8/20/2013	SHL	0.09	0.09	IOWATER	0.1	0.1
8/22/2013	SHL	0.13	0.24	IOWATER	0.3	0.6
9/12/2013	SHL	0.15	0.25	IOWATER		0.4
9/16/2013	SHL	0.12	0.14	IOWATER	0.2	0.3
	Mean	0.288	0.2215		0.3	0.3
	Median	0.145	0.14		0.153333333	0.1875
	St. Dev.	0.380202	0.238973132		0.1	0.1

CHAPTER 6

CONCLUSION

The primary goal of this project was to identify and recommend cost-effective methods and procedures for gathering information on sediment concentrations in runoff and receiving waters adjacent to Iowa DOT construction sites on major roadways. The main hypothesis reinforced the use of an acrylic transparency tube as a measurement of water clarity analysis in lieu of the turbidimeter for basic, initial water monitoring and data collection purposes. As an alternative to no data collection at all, the transparency tube serves as a cost-effective, relatively reliable tool for initial data collection. If, for regulatory purposes, a higher level of accuracy is required, the transparency tube can serve as a baseline for data collection, which can then be augmented by use of a turbidimeter. However, when no resources or tools exist, the acrylic transparency tube can serve as a basic method of rapid, on-site data collection.

While several states assessed as part of the project literature review require turbidimeter measurements taken from active construction sites, few – if any, provide guidance on sampling protocols, frequencies, recommended sampling locations, and handling procedures. In the case of Washington State, transparency tube measurements are allowed as surrogate data. Given the significant cost savings and potential for agency-wide scalability, transparency tube measurements are recommended as an initial, economical means of collecting data from active construction sites. While precision may be a trade-off, ease of use and consistency will likely result in a more robust, reliable data set for regulatory compliance. Even though no regulatory requirements exist for sediment concentration in data, a transparency tube may be used to provide benchmarks and measure water quality impacts or improvements as stormwater management practices continue to evolve and expand on active construction sites. By setting measureable water quality goals, activities such as dewatering, sediment basin use, and other erosion or sediment control practices may be better assessed for overall performance during wet and dry weather.

Other options were also considered as cost-effective methods of data collection. Because of its relatively low cost for setup and analysis, Total Solids testing was conducted using both soil and water to assess the applicability of its use as indicators of water clarity. The results of both soil and water analysis indicate such tests are not adequate surrogates for transparency or turbidity measurements. Samples require a time lag for drying, and material suspended in water may not be accurately measured once completely dry. This may be due to organic matter lost to volatilization, but not destroyed. The result may skew final data. (Washington State University). When using samples that are not highly turbid, or relatively low in sediment concentration, this conversion may yield a low, unusable reading (Julien, P.Y., 2010). Using Total Solids Water test for water clarity does not seem useful for the four chosen sites because scheduled samples rarely had highly turbid samples. Furthermore, those samples which were more turbid, from triggered events, required a more rapid response time than Total Solids testing allows. Should a site require immediate corrective action, results from Total Solids testing would potentially not be available for more than 24 hours.

Settleable Solids was chosen as a method of comparing water clarity characteristics across soil horizons. Results indicate, albeit loosely, that a single transparency-to-turbidity conversion chart may be used as a quick reference for field data collection. Further data may be collected to reinforce or refute this assessment. For the sake of this study, it serves as initial, further recommendation and reinforcement for considering the use of acrylic transparency tubes for rapid, cost-effective data collection and sampling from active construction sites.

At the request of Iowa DOT, nutrient sampling occurred on two project sites: Ankeny and Waverly. In both instances, upstream nutrient concentrations were already well above statewide averages for both nitrates and phosphorus. While DOT sites were not found to be significant sources of additional nitrate load, phosphorus load may be a concern. In areas where flow becomes stagnant, nitrate levels may decrease due to volatilization. Conversely, phosphorus levels may increase due to concentration and limited flow. Regardless of scale, it is evident Iowa DOT does have an impact, albeit small in scale, to surface water quality and nutrient concentration. Scalable impacts and implementation may be an approach to improving water quality. Iowa DOT may consider applying phosphorus-free or reduced phosphorus fertilizers, or minimize soil loss from construction sites as a means of further reducing impacts to water quality.

The results from our research shows that it is possible to use an acrylic transparency tube instead of a turbidimeter reliably, however the benefits of simple, rapid data collection from a transparency tube come at the cost of the higher degree of accuracy and precision attained by collecting data with meters and lab-based procedures. In the instance of collecting data when no other information exists, the acrylic transparency tube is an ideal starting point. As stated previously in this report: should a higher degree of precision and or accuracy be required, once data is collected by means of an acrylic transparency tube, water monitoring professionals may consider lab-based analysis or use of a turbidimeter to further analyze samples taken from active construction sites. Table 16 displays the cost, time, and training needed comparison between the Hach 2100Q Portable Turbidimeter and acrylic transparency tube used in this experiment. Not only is the transparency tube just as accurate and precise, it is more cost effective, faster, and takes less training than the turbidimeter. Because erosion and sediment control is a concern to highway construction site managers, measuring surface water clarity is a basic method to determine if water quality conditions vary from day to day, or based on triggered storm events.

According to the work by Fermanich, a turbidity (transparency) tube can be exchanged with a nephelometer (turbidimeter) with a confidence of between 0.99 and 1.0 when using formazin standards. The data from this study shows using an acrylic transparency tube using stream surface water can be compared to turbidimeter readings with a confidence of 0.91 in the lab and 0.71 in the field. Samples taken in the field must be re-suspended before testing in the lab. In addition, samples received by the lab have holding time, which can cause measurements to differ from those taken immediately, in the field. Three trials were done on the turbidimeter with bottled sample while only one reading was taken in the field with the transparency tube. It would be recommended for field-based sampling to also include three readings per sample.

Figure 63 contains the equations used to convert samples from both triggered and scheduled water monitoring activities. Appendix 1 contains the original conversion chart developed for top soil by the University of Wisconsin Extension (2006). Based on the results of the study, these conversion charts in Table 17 are recommended for use in conjunction with samples collected and measured with acrylic transparency tubes. The units on the left side are transparency tube measurements in centimeters, which correspond to turbidity measurements in NTU, on the right. The variation between conversions is based on data collected and conditions observed during the two types of sampling activity.

TABLE 16: COMPARISON OF TURBIDIMETER & ACRYLIC TRANSPARENCY TUBE

Equipment	Price	Time of Use* (minutes)	Training Needed
Hach 2100Q Portable Turbidimeter	*$1309*	*12.45*	*need to read 16 page manual*
Acrylic Transparency Tube (60 cm)	*$38.50*	*.30 - 1.5*	*need to read 2 page manual*

*Calibration for turbidimeter reading, assembly, etc.

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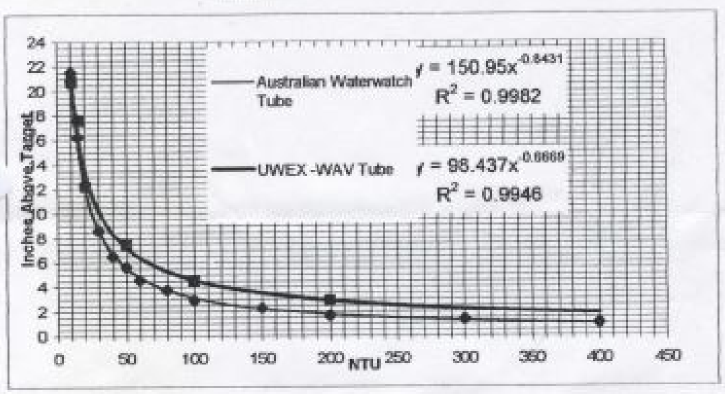
NTU	Australian Turbidity Tube Inputs from Mike Gardner (inches above target)	UWEX-WAV Tube Inputs from Jim Peterson	
400	1		
300	1.313		
200	1.625	2.875	
150	2.250		
100	2.938	4.5	
80	3.750		
60	4.563		
50	5.625	7.5	Put line at
40	6.500		17 inches
30	8.625		for 15 NTU
20	12.375	12.25	per JP&KF
15	16.250	17.625	17.00
10	21.500	20.75	

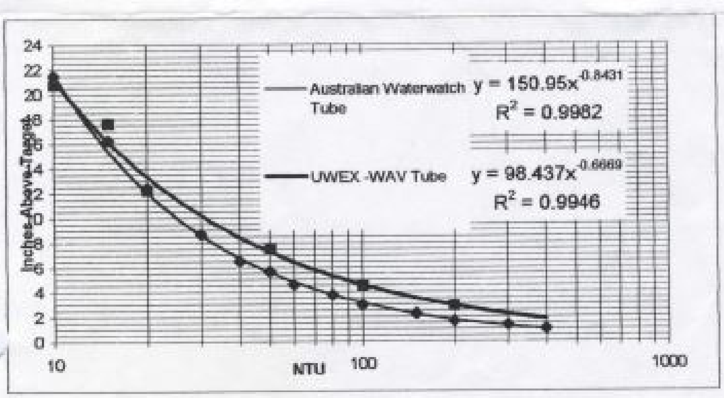
UWEX-WAV
y = 98.437x^(-0.6669)

NTU	Predicted inches	Difference
200	2.876	0.001
150	3.484	
100	4.566	0.066
80	5.298	
60	6.419	
50	7.249	-0.251
40	8.412	
30	10.191	
20	13.356	1.106
15	16.180	-1.445
10	21.204	0.454

Australian Tube
y = 150.95x^(-0.8431)

NTU	Predict in	Diff.
400	0.966	-0.034
300	1.231	-0.082
200	1.733	0.108
150	2.209	-0.041
100	3.109	0.171
80	3.753	0.003
60	4.783	0.220
50	5.577	-0.048
40	6.732	0.232
30	8.580	-0.045
20	12.076	-0.299
15	15.391	-0.859
10	21.664	0.164





turbidity tube scale.xls

Figure 61 – Scan of source data for transparency tube conversion.

NTU Conversion Chart for Field-based Transparency Measurement

Triggered Sampling

$y=265.9x^{-0.683}$

Transparency (in cm)	Turbidity (in NTU)
2.77	800
2.89	750
3.03	700
3.19	650
3.37	600
3.57	550
3.81	500
4.10	450
4.44	400
4.87	350
5.41	300
6.12	250
7.13	200
8.68	150
11.45	100
13.93	75
18.38	50
23.45	35
29.51	25
34.36	20
41.83	15
55.17	10
59.29	9

Scheduled Sampling

$y=156.11x^{-0.557}$

Transparency (in cm)	Turbidity (in NTU)
3.77	800
3.91	750
4.06	700
4.23	650
4.43	600
4.65	550
4.90	500
5.20	450
5.55	400
5.98	350
6.51	300
7.21	250
8.16	200
9.58	150
12.01	100
14.09	75
17.66	50
21.55	35
25.99	25
29.43	20
34.54	15
43.29	10
45.91	9

CHAPTER 7

RECOMMENDATIONS

As state and federal regulators consider further regulations on water clarity and water quality standards, it may be prudent to think of embracing characteristics unique to Iowa when addressing erosion and sediment control. There are twelve main soil types in Iowa consisting of loess, glacial till, and alluvial materials (Iowa State University, 2013). For the sake of this project, six soil samples were collected from across Iowa as representative of the basic soil types found in A, B, and C horizons across Iowa. Bob Vbora, soil scientist with the Natural Resource Conservation Service (NRCS) assisted with this effort. In the future, research concerning how these different soil types respond to erosion and sediment control methods as well as the soils response to different water quality testing methods (Total Solids and Setteable Solids) may be explored in further detail. While overall, the soil profiles studied as part of this project behave relatively similarly, there are unique characteristics in loess soils located in western Iowa, and sandy soils of the southern drift plain which may skew the data. However, on a whole, most Iowa soils were found to settle in a similar enough fashion in one liter of water to rely with confidence on one conversion chart for comparing turbidity to transparency.

As part of this project, a Quality Assurance Project Plan (QAPP) is recommended to guide those in better decision processes making through a practical, replicable approach to collecting relevant water quality information. This document can serve as a general reference for sampling and testing methods implemented during this study, and recommended for future use. The methods are based on both professional and volunteer water quality monitoring practices endorsed by the Iowa Department of Natural Resources, U.S. Geological Survey, ASTM International testing standards and U.S. Environmental Protection Agency (EPA).

Without any existing state or federal requirements for sampling and water quality monitoring, efforts to collect such data from active construction sites are voluntary at this point in time. Lack of regulatory requirements can make funding for such efforts a lower priority for publicly funded agencies. As a result, any proactive measures to gather information from active construction sites needs to be effective as well as inexpensive. Mandate or no, the purchase of a turbidimeter is cost prohibitive for organizations or individuals. By collecting water quality data through the use of acrylic transparency tubes, Iowa DOT can achieve a high level of accuracy in the data collected, without investing heavily in equipment.

Because these state and federal regulations may eventually require water quality monitoring for active construction sites, those preparing to measure clarity have an alternative to the expense of the digital turbidimeter. Before these regulations are in place, proactive measures can be taken to manage construction site runoff to protect the quality of water in Iowa, benefitting all Iowans. By collecting water quality data from DOT construction sites, the Agency is also able to react and respond to water quality concerns that directly impact the local water resource on a project site in an effective, affordable manner.

APPENDIX 1. WISCONSIN CONVERSION CHART

Transparency Value Conversion Chart

Centimeters	Inches	Transparency Value*
6.4 to 7.0	2.5 to 2.75	240
7.1 to 8.2	2.76 to 3.25	185
8.3 to 9.5	3.26 to 3.75	150
9.6 to 10.8	3.76 to 4.25	120
10.9 to 12.0	4.26 to 4.75	100
12.1 to 14.0	4.76 to 5.5	90
14.1 to 16.5	5.6 to 6.5	65
16.6 to 19.1	6.6 to 7.5	50
19.2 to 21.6	7.6 to 8.5	40
21.7 to 24.1	8.6 to 9.5	35
24.2 to 26.7	9.6 to 10.5	30
26.8 to 29.2	10.6 to 11.5	27
29.3 to 31.8	11.6 to 12.5	24
31.9 to 34.3	12.6 to 13.5	21
34.4 to 36.8	13.6 to 14.5	19
36.9 to 39.4	14.6 to 15.5	17
39.5 to 41.9	15.6 to 16.5	15
42.0 to 44.5	16.6 to 17.5	14
44.6 to 47.0	17.6 to 18.5	13
47.1 to 49.5	18.6 to 19.5	12
49.6 to 52.1	19.6 to 20.5	11
52.2 to 54.6	20.6 to 21.5	10
>54.7	>21.6	<10

What Do These Turbidity / Transparency Values Mean?

All streams have background turbidity/transparency, or a baseline standard for a natural amount of turbidity /transparency. Fish and aquatic life that are native to streams have evolved over time to adapt to varying levels of background water clarity. For example, native fish and aquatic life in the Mississippi River are very happy with their murky environment. What causes problems in any stream or river are unusual concentrations of suspended particles and how long the water stays at a deviated level. When you collect transparency samples, it is important to note any fluctuations in values, which can help detect trends in water quality.

Time is probably the most influential factor in determining how turbidity affects the aquatic environment. The longer the water remains at unusually high values, the greater effect it has on fish and other aquatic life. Fish in particular become very stressed in waters that remain highly turbid for a long time. Signs of stress include increased respiration rate, reduced growth and feeding rates, delayed hatching and in severe cases, death. Fish eggs are ten times more sensitive to turbidity than adult fish. To further understand how time and turbidity impact fish, look at the graph that is included: "Relational Trends of Fresh Water Fish Activity to Turbidity Values and Time".

High turbidity levels affect humans, too. Acceptable turbidity levels for recreation is 5 NTU and acceptable levels for human consumption ranges from 1-5 NTU.

Water Action Volunteers is a cooperative program between the University of Wisconsin-Extension and the Wisconsin Department of Natural Resources. For more information, contact the Water Action Volunteers Coordinator at 608/264-8948.

*Roughly NTUs

(University of Wisconsin Extension Service, 2006)

CHAPTER 9

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