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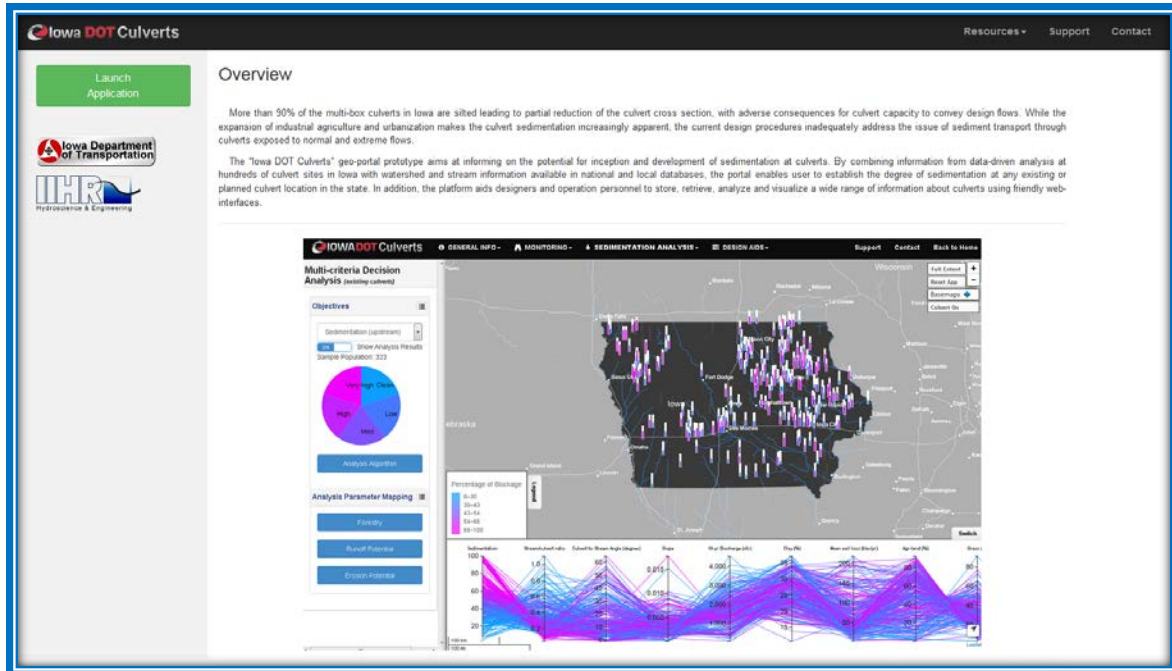
TRANSFER OF THE IOWA DOT CULVERTS WEB-TOOL PROTOTYPE TO IOWA DOT MAINFRAME

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16. Abstract

A data-driven approach embedded in a web-based problem-solving environment was developed through a previous Iowa Highway Research Board IHRB project (IHRB TR-655) for providing the critical information needed for designing and maintaining culverts operational and free of sedimentation. The full description of the web-tool concept, cyberinfrastructure, and its functional and operational features are described in the report of the aforementioned project. The web-tool was presented at several state, regional and national events and was well received by a wide variety of potential users. Based on this positive feedback the TR-655 Technical Advisory Committee suggested to transfer the prototype portal within Iowa Department of Transportation (IDOT) information technology infrastructure for internal usage by IDOT personnel associated with culvert design and operations. The IHRB project TR-744 provided the funds for customizing the prototype and transitioning the culvert web-tool in the IDOT computer environment. The web-tool makes relevant pre- and post-construction culvert data easily accessible in one place irrespective of their provenance. User-friendly portal interfaces allow users to prepare a systematic plan for culvert monitoring, and offer means for quantitative assessment of the potential for sediment deposit formation.

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Abstract

Sedimentation is one of the major operational hazards for culverts located in Midwestern areas of United States. Currently, there are no systematic efforts for mitigating detrimental effects of sediment blockage at culverts, as the problem involves complex and interlinked environmental processes that are difficult to investigate and solve with conventional approaches (e.g., experimental methods and physical modeling). Facilitated by an Iowa Highway Research Board project (TR-665) we developed a new, innovative solution for addressing culvert sedimentation using a data-driven approach. This approach enables identification of culvert sedimentation drivers and quantifies the relationships between drivers and culvert sedimentation severity, making use of an extensive set of multi-disciplinary data. The data analysis and management tools are embedded in a web-based platform, the IowaDOT Culverts, equipped with user-friendly interfaces and interactive visualizations for facilitating analysis and forecasting of sedimentation at multi-box culverts across Iowa.

The web-tool was presented at several state, regional and national events and was well received by a wide variety of potential users. Based on this positive feedback the TR-655 Technical Advisory Committee suggested to transfer the prototype portal within Iowa Department of Transportation (IDOT) information technology infrastructure for internal usage by IDOT personnel associated with culvert design and operations. The prototype Iowa DOT Culverts platform has been hosted on a server at IIHR-Hydroscience & Engineering, The University of Iowa. The current location of the web-tool is on an on IDOT internal url: http://culverts. Following several initial meetings with the Information Technology Division's Office of Highway Support office personnel, an adjusted configuration of the IDOT Culverts tool was devised such that the transferred version of the environment is free of databases and software that are not supported on a regular basis. Care was taken that the applied adjustments preserve the functions, look and feel of the originally-developed prototype. For this purpose, adaptations, switching of components and software scripts were applied to the original software components as necessary. The final components for supporting the tool along with the installation and troubleshooting instructions are provided in Appendix A of this report. A step-by-step guidance for the use of the tool functionalities are described with snap-shots of the interfaces in Appendix B.

The transferred geo-tool enable IDOT users to: a) stay informed on culvert related activities (e.g., updates on the status of sedimentation at individual culvert sites for resource planning purposes); b) serve as a living repository that can be mined to infer aspects of current designs in relationship with the location of the culvert in diverse geographic areas. The web-tool also allows users to explore various relationships between a culvert status and its evolution in time, commensurate with the changes in the watershed (e.g., correlating changes in the landscape due to socio-economic activities with the changes in conveyance capacity of the culverts over time). The transferred portal usefully complements current culvert design specifications with conceptualized ground-truth information that correlates sedimentation at culverts with their geometry, stream, and watershed characteristics draining to the culvert site, irrespective of its location in the state.

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1. BACKGROUND

One of the objectives of the previous IHRB TR-665 project was to develop a prototype web-based problem-solving environment for providing the critical information needed for designing and maintaining culverts operational and free of sedimentation. The main objective of the present project was to transfer the web-based application (portal) originally developed on servers located at IIHR-Hydroscience & Engineering, The University of Iowa (see Figure 1) to IDOT computer environment for routine operation.
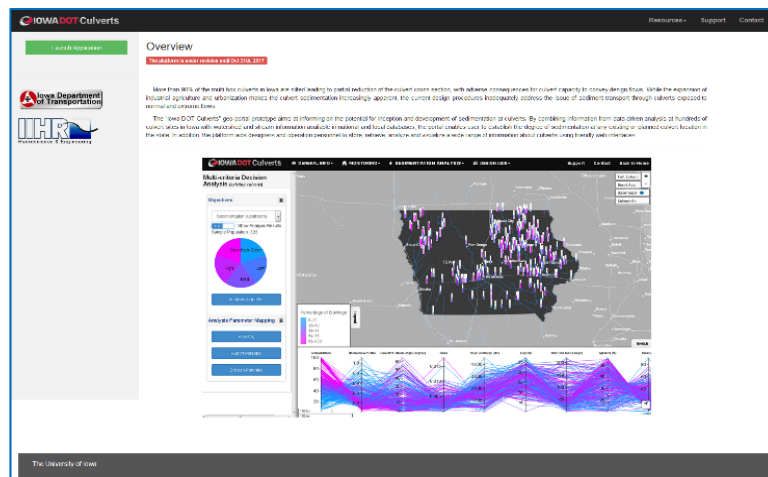
Figure 1. Landing page of the Iowa DOT Culverts web tool (when located on the http://iowawatersheds.org/culverts)

The web tool transferred with this project to IDOT is needed as sedimentation at culverts does not benefit from coherent design and monitoring mitigation guidelines being left on the fringes of the routine road maintenance for long years. For multi-box culverts located in flat, erodible watersheds, the most significant operational problem is sedimentation in the culvert vicinity. This is the case for the highly erosive Iowa landscape that can lead to situations whereby some of the barrels can become partially filled with sediment. Surveys of Iowa county and Iowa Department of Transportation (IDOT) engineers conducted by IIHR_Hydroscience & Engineering (IIHR) in 2009 and 2013 suggest that more than 95% of Iowa culverts are silted. The sedimentation concern is widespread in the nation, from California to Pennsylvania and from Wisconsin to Florida (Rowley, 2014).

Silting can considerably reduce the capability of the culvert to handle larger flow events as the partial blockage of the structure could severely impair the hydraulic capacity to convey design flows. Obstruction of the culvert inlet can cause severe damage to both the transportation structure (e.g. overtopping of road and culvert) and upstream headwater areas (e.g. flooding). Not surprisingly, the occurrence of culvert sedimentation is a major concern for road maintenance authorities in many Midwest areas. Cleaning the accumulated sediment is one of the costliest problems in culvert operations in Iowa, as the siltation develops quickly—the sedimentation process attains its stable form in no more than four or five years—and might require repeated cleanups. Lack of guidance on how to mitigate sedimentation leaves no alternative other than the costly and labor-intensive mechanical cleaning of sediment whenever it becomes critical.

The complexities of the watershed sediment dynamics continuously shaped by anthropogenic impacts exceed the problem-solving capabilities of the available experimental, analytical, or numerical simulation-based investigations. In order to provide watershed managers and structural engineers in charge of sedimentation at culverts with information needed to make decisions, we proposed an alternative and robust tools for diagnostic. Specifically, we adopted a data-driven approach embedded in a web-based problem-solving environment that can provide the critical information for planning, designing, and maintaining culverts that is also compatible with the stream environment. The proposed method maintains the holistic, systems approach of the problem investigation but it does so with cost-efficient and effective means. The method can only be applied in data-rich watersheds or

in areas where surrogates for that data are available. Fortunately, the surrogates are increasingly available through the expansion of remote sensing technologies that survey watershed properties over large scales at a fraction of the cost compared with conventional observation means.

To make the data and information regarding sedimentation at culverts easily accessible and functional, we designed a web-based geo-portal that assembles in one place pre- and post-construction data and information, irrespective of their provenance. The portal enables the four workflows illustrated in Figure 2. In essence, the workflows facilitate the following activities:

(1) storage and query of culvert specifications and ancillary information;

(2) monitoring of sedimentation at culverts using in-situ or remote sensing technologies;

(3) analysis of the sedimentation at culverts; and

(4) support the design of the culvert by forecasting the sedimentation potential for any culvert site.

User-friendly portal interfaces allow users to prepare a systematic plan for culvert monitoring, and offer means for quantitative assessment of the potential for sediment deposit formation. The workflows can be applied to existing or new culvert sites, therefore assisting both field operation and design purposes. Full details on the TR-665 project can be found in Muste and Xu (2017a).
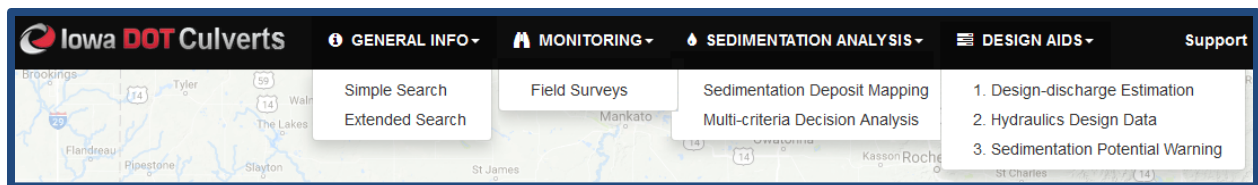
Figure 2. The four workflows residing on the Iowa DOT Culverts web tool

The IDOT Culverts tool was presented at several state, regional and national events [e.g., STIC dissemination workshops in Iowa, MINK Local Roads Meeting in St Joseph (MO), and AASHTO TC on Hydrology & Hydraulics (Des Moines), and Transportation Research Board 2017 Meeting (Washington D.C.)]. During the presentations and follow up discussions, participants had positive feedback on the usefulness of the new web-platform for both the design and monitoring activities. The Technical Advisory Committee of the project (i.e., D. Claman, B. Younie, and G. Parker) suggested to transfer the prototype portal within Iowa DOT cyberinfrastructure for routine usage, long-term maintenance, and future updates.

2. IDOT CULVERTS TOOL FUNCTIONS

The transferred Iowa DOT Culverts web tool is currently residing at http://culverts. The tool works atop of a variety of data sources (time series, statistical analyses, maps, and other site-specific characteristics) that are stored in various formats in multiple data provider repositories. Rather than acquiring the above-mentioned data and information from individual sources (such as IDOT, Department of Natural Resources, Environmental Protection Agency, or US Geological Survey) piece-by-piece for each culvert site, we decided to develop tools to access of all the relevant information sources from one place, a kind of one-stop-shop, culvert-centered database. The information can be retrieved on-the-fly from this central data and information repository whenever needed and subsequently subjected to further analyses, mostly making inferences from the existing data (i.e., data-driven modeling). The previous IHRB-funded project, TR-665, carried for prototyping the IDOT Culvert web tool entailed the following functions (Muste and Xu, 2017a):

A. Review of the essential physical processes involved in culvert sedimentation and identification of the contributing factors and key drivers of the problem.

B. Development of a comprehensive culvert sedimentation data repository by integrating culvert sediment observations (obtained through field inspections and sediment mapping onto aerial imagery) with selected drivers identified in the previous objective.

C. Quantification of the sedimentation occurrence at culverts based on the outcomes of Multiple-Criteria Decision Analysis (MCDA) and integration of the research outcomes obtained in the previous two objectives into a web-based portal for forecasting culvert sedimentation in Iowa.

Erosion and its downstream transport are typically characterized by sediment yield which quantifies the erosion amount delivered to a specific location. Of the dislocated material, only a fraction enters the drainage area channel system (Da & Bartholic, 1997). The in-stream sediment transport entails two transport modes, namely suspended load and bed load (Karim, 1981). Finally, the culvert design discharge is directly related to sediment deposition at culverts (UDOT, 2017). The parameters selected for end-to-end analysis of the sediment transport processes are provided in Table 1.

Table 1. Main drivers of the sedimentation transport

PARAMETER	ASSOCIATED PROCESSES/DRIVERS	DATA SOURCE(S)
Soil type	Sediment particle size & suspended load	SSURGO, StreamCAT
Channel density	Sediment delivery ratio	NHD Plus
Watershed slopes	Sediment delivery ratio, channel flow	NHD Plus
Land cover	Sediment delivery ratio	StreamCAT
Design discharge	Sediment transport rate	USGS (Eash method)

The description provided above are the essentials the mechanisms responsible for watershed erosion and sediment transport at the culvert locations. The companion problem to erosion and sediment transport is sedimentation. Most streams carry a sediment load and tend to deposit this load when their velocities decrease. The near-culvert (local) processes are strongly related to the structure-stream interaction whereby the culvert structural characteristics play an important role in settling and trapping the sediment yield generated upstream from the culvert location. The parameters involved in sediment deposit formation are listed in Table 2.

Table 2. The main parameters involved in the local accumulation of sediment at culverts

PARAMETER	ASSOCIATED PROCESS	DATA SOURCE(S)
Stream-to-culvert width ratio	Culvert morphodynamics	SIIMS, aerial imagery
Vegetation presence	Sediment deposit growth	Field survey, aerial imagery
Upstream riparian corridor	Streambank erosion	StreamCAT
Angle of incidence	Culvert morphodynamics	Aerial imagery
Culvert control	Culvert morphodynamics	SIIMS

In the TR-665 development study, the independent and dependent variables were integrated in one digital repository hosted in a web-GIS environment. The digital repository entails culvert sediment observations (quantification of the sedimentation severity), multiple structural specifications (culvert width, length), and environmental variables (e.g. soil erodibility, runoff, channel vegetation, and watershed slope) in the watershed and the stream vicinity. Integration of the above information required: (1) spatial join to connect culvert locations with its pertaining watershed characteristics, and, (2) classification of response variables for quantification of the degree (severity) of sediment blockage at culverts. The digital repository is connected to a web-based Content Management System (CMS), in which users can easily quantify and submit culvert sediment observations, as well as access independent variables produced by various third-party sources. The repository serves as the foundation for subsequent analyses. Table 3 provides details on the data sources.

Table 3. List of data sources.

DATA SOURCE	PROVIDER	DATA DESCRIPTION	DATA TYPE
Structure Inventory and Inspection Management System (SIIMS)	Iowa DOT	Culvert structural specifications	Predictor
National Hydrography Dataset (NHD) Plus	USGS	Digital river networks and hydrologic connectivity	Predictor
Watershed Boundary Dataset (WBD)	USGS	Digital watershed boundary and attributes	Predictor
Stream-Catchment (StreamCat) Dataset	USEPA	Watershed characterization (ecology aspect)	Predictor
Revised Universal Soil Loss Equation (RUSLE)	USDA	Total annual soil loss	Predictor
Annual Stream Exceedance-Probability Statistics	USGS	Estimate culvert design discharge	Predictor
Aerial Imagery	Multiple sources	Orthorectified images (various spatial-temporal resolution)	Response variable
Iowa Culvert Sediment Observation Database	IIHR	Cross-sectional blockage and sediment deposit area	Response variable

At the core of the web tool is a MCDA software that systematically identifies the likelihood of culvert sedimentation as a function of stream and culvert geometry, along with landscape characteristics, in the culvert drainage area. MCDA advises on the culvert sedimentation potential, thereby directly aiding in the design and operation of the multi-box culverts. The MCDA is an approach that uses quantitative and qualitative data, along with expert judgment, to support decisions even is the data is not abundant (Vulevic & Dragovic, 2017). The MCDA pertains to the cross-disciplinary research that looks for ways to provide computer support to solving space-related decision problems through enhancing human capabilities to analyze, envision, reason, and deliberate (Andrienko et al., 2007). The MCDA usage in the present context has the following purposes:

(i) Ranking environmental and structural drivers behind culvert sedimentation using feature selection techniques.

(ii) Developing quantified relationships between culvert sediment degrees and key drivers within each region using deductive hydrological classification.

This project entails transferring the outcomes of tasks B and C to the Iowa DOT Information Technology environment for long-term maintenance and periodic updating.

3. WEB TOOL TRANSFER

3.1. Overview of the components

The cyberinfrastructure and components of the "Iowa DOT Culverts" web tool are extensively described in Xu (2015), Xu et al. (2015), and Muste & Xu (2017a) therefore only salient features of the geo-portal are provided in this section. Culvert monitoring and design are based on a variety of data sources (time series, statistical analyses, maps, and other site-specific characteristics) that are typically stored with data providers in various formats. After construction, more data is produced through periodic culvert monitoring programs that report useful information on operation performance and associated problems. The post-construction data and information is especially important if they cover aspects that were insufficiently addressed in the design stage (such as the effect of sedimentation, debris, and environmental factors). These multiple variables are widely available for all U.S. territories but stored in various formats and multiple repositories, which makes their handling difficult.

In this study, phase independent and dependent variables were integrated in one digital repository hosted in a web-GIS environment. The digital repository entails culvert sediment observations (quantification of the sedimentation severity), multiple structural specifications (culvert width, length), and environmental variables (e.g. soil erodibility, runoff, channel vegetation, and watershed slope) in the watershed and the stream vicinity. Integration of the above information required: (1) spatial join to connect culvert locations with its pertaining watershed characteristics, and, (2) classification of response variables for quantification of the degree (severity) of sediment blockage at culverts. The digital repository is connected to a web-based Content Management System (CMS), in which users can easily quantify and submit culvert sediment observations, as well as access independent variables produced by various third-party sources. The repository serves as the foundation for subsequent analyses.

The Iowa DOT Culverts geo-portal comprises a front-end and a back-end component (the term "front-end" is referring to user's computer, while "back-end" indicates the server backing the web applications; front-end is the client-side, while the back-end is the server-side section of a web platform). As is common in most modern web-application templates, the Iowa DOT Culverts tool adopts a three-tier architecture that includes the following components: (1) presentation, (2) logic, and (3) data. The presentation tier is primarily rendered at the front-end in a user's web or mobile browser. It contains platform elements that a user can see and interact with. The logic management component contains a front-end MVC that improves fluid web page design and two-way data-binding. The logic tier is responsible for organizing the data, assembling the services based on the relationship between the user scenarios and the models, and for providing the necessary information requested by the presentation tier. To ensure platform reliability, flexibility, extendibility, modularity, and maintainability industrial design patterns and architecture patterns (e.g. model–view–controller (MVC) and model-view-view-model (MVVM) software) were applied in the system development. Figure 3 and Table 4 illustrate the architecture, and the web and the associated GIS technologies.
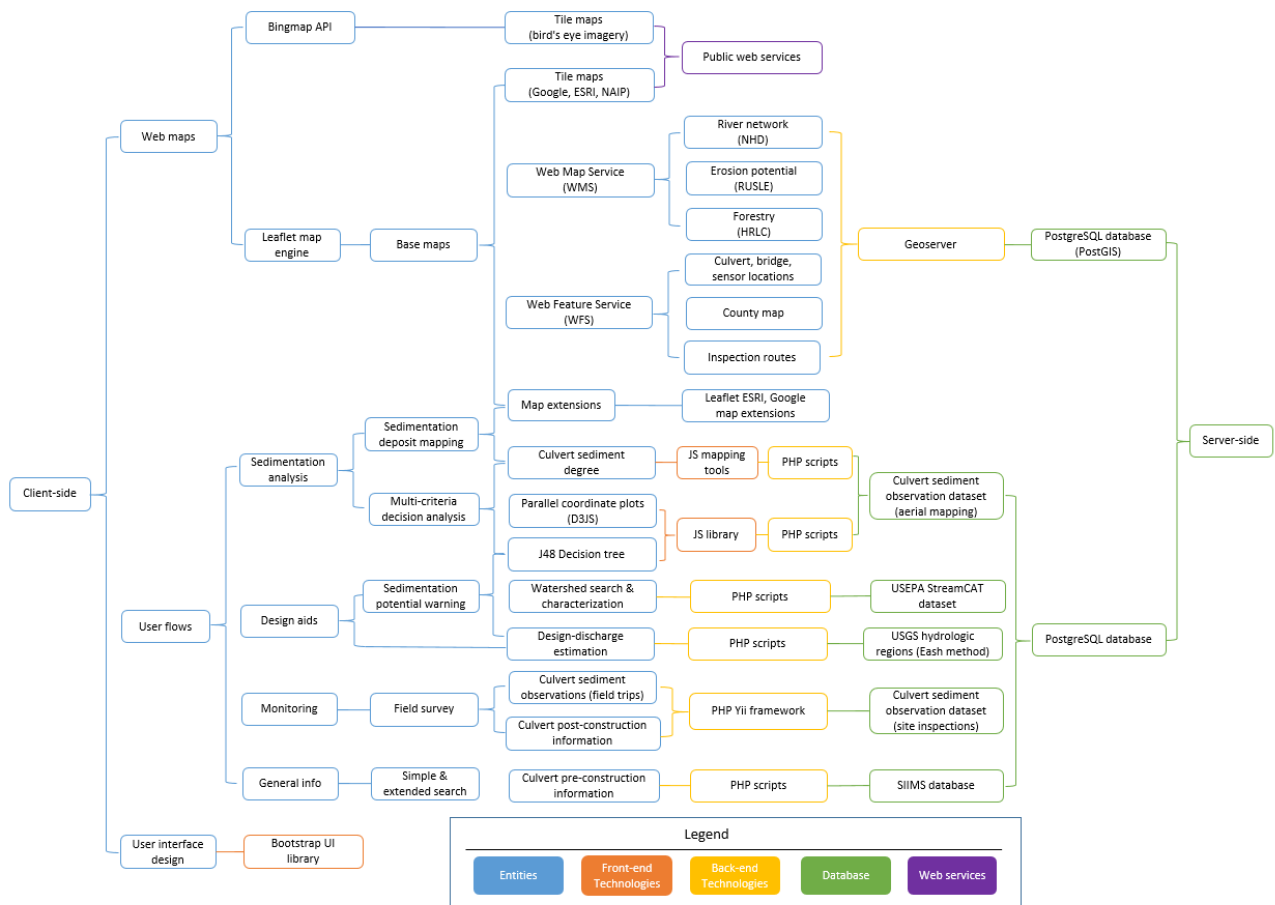
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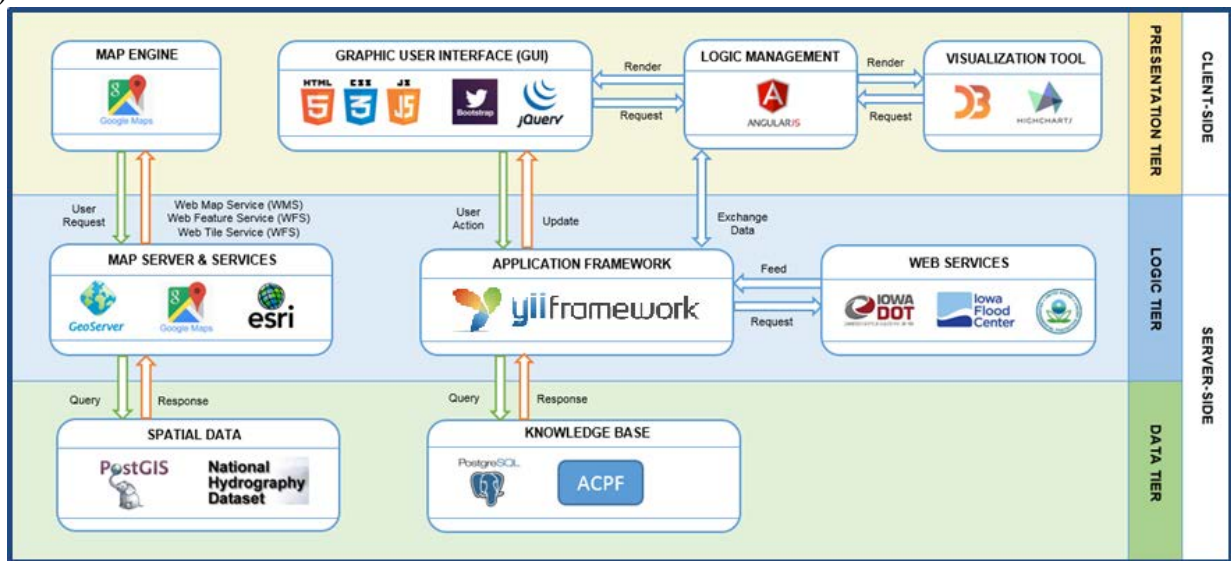
b)

Figure 3. Iowa DOT Culverts portal: a) architecture; b) user-server flux (Xu et al., 2015).

Table 4. Summary of software components, their role, and associated programming languages.

COMPONENT	ROLE	TECHNOLOGY
Development Technology		
Back-end		
Apache HTTP Server	Web Server	-
Apache Tomcat	Web Server	-
Geoserver	GIS Map Server	Java
PostGres & PostGIS	RDBMS	SQL
PHP YII framework	Backend MVC	PHP
Front-end		
Jquery	cross-platform JS library	Javascript
Jquery-UI	Jquery UI design library	Javascript
Bootstrap	UI design library	Javascript
Bootstrap	Bootstrap switch	Javascript
Leaflet	Map engine	Javascript
Leaflet-Esri	Leaflet plugin	Javascript
Leaflet-Google	Leaflet plugin	Javascript
Leaflet-Draw	Leaflet plugin	Javascript
Highchart	Plots	Javascript
Highchart-more	Plots-extension	Javascript
D3JS	Data visualization	Javascript
D3JS_leaflet	Leaflet plugin	Javascript
Leaflet open-weather	Leaflet plugin	Javascript
Google map API	Map engine	Javascript
typeahead.js	Text autocomplete	Javascript
BingMap API	Map engine	Javascript
Leaflet geolocator	Leaflet plugin	Javascript
Geolocator control	Leaflet plugin	Javascript
Leaflet routes	Leaflet plugin	Javascript
Lagodiuk decision tree	Javascript machine-learning	Javascript
UI design double scroll	Jquery UI design	Javascript
Three-js	3D visualization	Javascript
Data Sources		
Iowa Flood Center	Stage sensor	PHP web-service
United States Geological Survey	Stage/discharge sensor	USGS web-service
USGS SSURGO	Web map service	Rasters
RUSLE	Web map service	Rasters
High Resolution Land Cover	Web map service	Rasters
SIIMS	Culvert information	CSV
EPA StreamCAT	Watershed characterization	CSV/Web services

3.2   Overview of the tool workflows

There are four sets of workflows hosted on the current Iowa DOT Culverts platform: 1) General Info, 2) Monitoring, 3) Sedimentation Analysis, and 4) design aids. These tools and functions are operated through user-friendly interfaces that do not require computer science of technology knowledge such as the user can concentrate on the engineering problem of interest. The flux of information for each of the workflow sets is succinctly presented next.

"General Info" workflows. Information about the culverts is retrieved through two search engines. Each of the search engines retrieves the boundary and drainage area upstream of a selected culvert and can retrieve any point of interest (POI) on the Iowa state map. With this arrangement, watershed characteristics for existing and future culvert locations can be retrieved. The dataset for existing culverts contains pre-construction and post-construction culvert data. The flux of data and information for this set of workflows is presented in Figure 4.
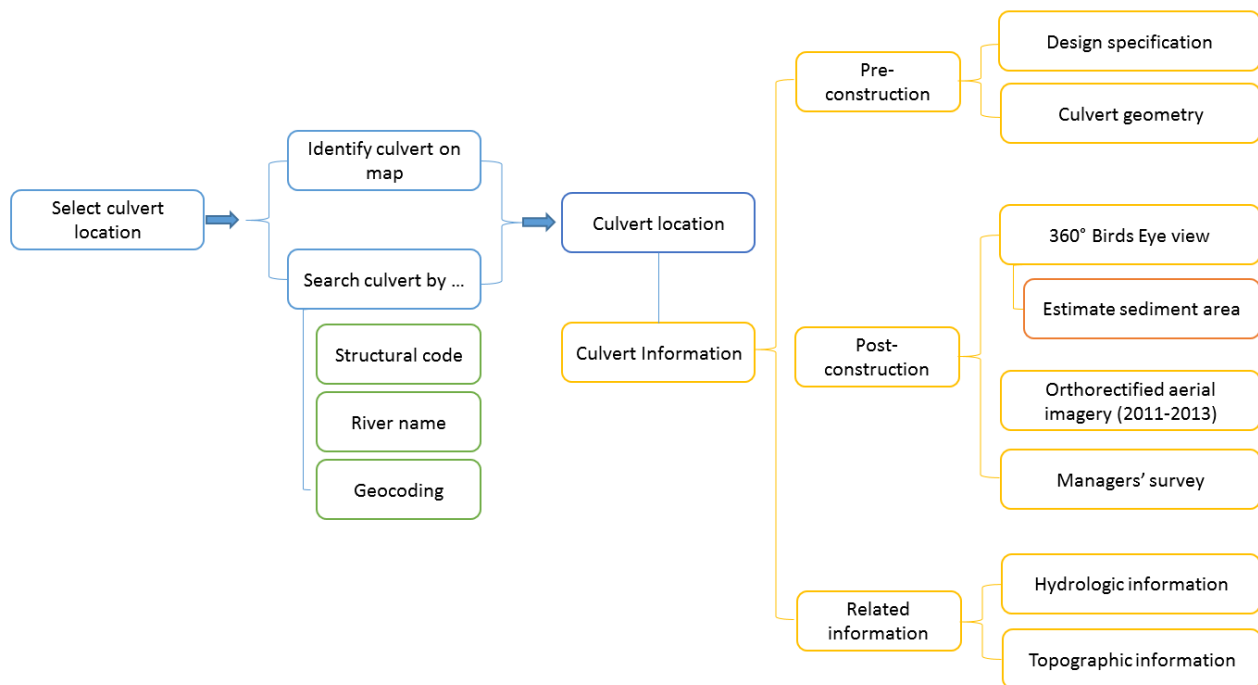

Figure 4. Flow diagram for the "General info" workflow.

"Monitoring" workflows. This cluster of tools is assembled with the intent to aid culvert monitoring activities. Specifically, the workflow assists users to inspect a culvert site and observe time series and details of the surrounding terrain provided from LiDAR maps. The flow of information for this workflow is illustrated in Figure 5. Useful tools for navigating to sites and organizing field campaigns that cover specific purposes are also embedded in this workflow.

"Sedimentation Analysis" workflows. This is the central group of cybertools in the platform that are solely used to quantify and evaluate sedimentation as an end-to-end process, i.e., the "Sedimentation Deposit Mapping" and "Multi-Criteria Decision Analysis" workflows, respectively. The first workflow contains several tools for mapping on aerial photographs or alternative maps for the estimation of the degree of sedimentation that are subsequently used in the MCDA phase. The "Multi-Criteria Decision Analysis" (MCDA) workflow quantifies the relationship between the degree

of sedimentation at culverts and the predictor variables integrated in the portal's database. The MCDA's main objective is to develop quantitative relationships between the degree of culvert sedimentation and the key process drivers within the drainage area of the culvert using deductive hydrological classification powered by machine-learning and visual-analytics techniques. The overall flux of information supporting the "Sedimentation Analysis" workflow is illustrated in Figure 6.
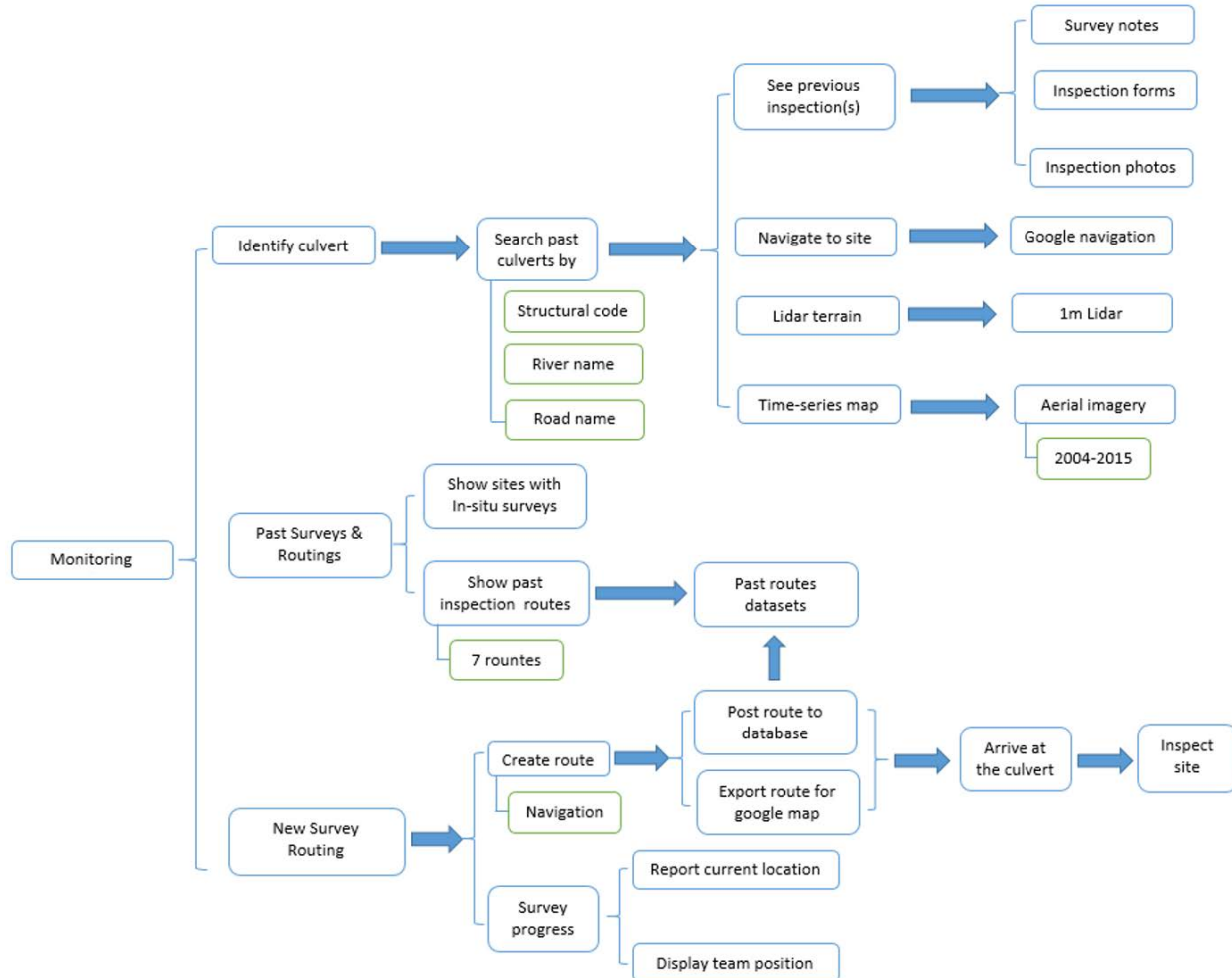

Figure 5. Flowchart for the "Monitoring" workflow

"Decision Aids" workflows. This set of workflows is practically the corollary of all the developments carried out through the prototype web-tool study. The toolset includes useful aids for the culvert designer or operation personnel by providing the data needed for the estimation of the culvert design discharge and assessment of the degree of sedimentation at the culvert construction site. The tools can be used to estimate these variables at existing or future culvert sites. Based on the degree of sedimentation provided by the forecasting tool, the user can decide if the culvert needs to be re-evaluated in terms of hydraulic design or to be associated with protective measures to mitigate sedimentation. These measures can include practices that reduce erosion and sediment transport in the upland areas or can recommend self-cleaning solutions such as those developed in a companion study on culverts (Muste and Xu, 2017b). The overall flux of information for this set of workflows is provided in Figure 7.
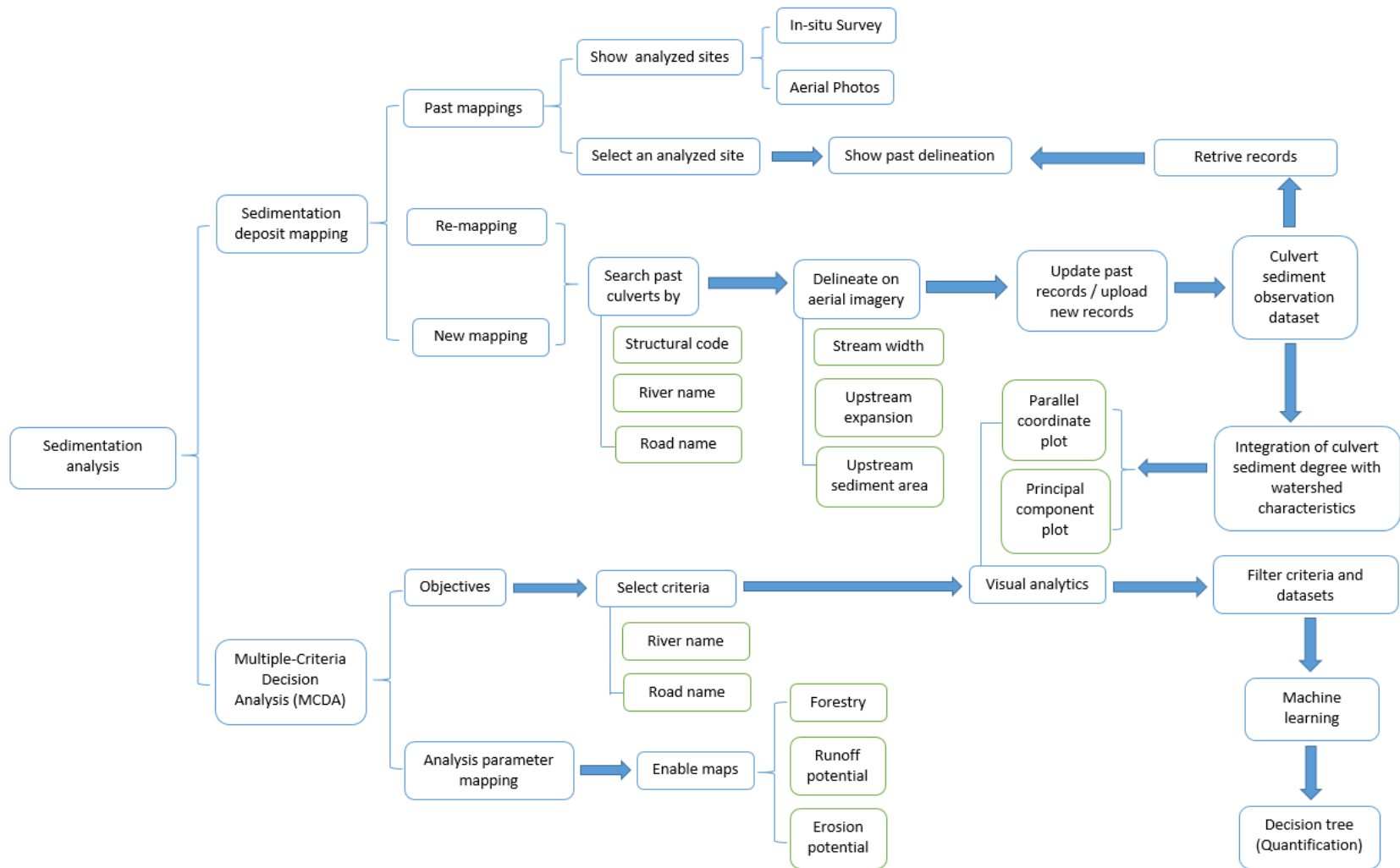
Figure 6. The tree-like structure used for "Sediment Analysis" applied to the sedimentation at culverts.
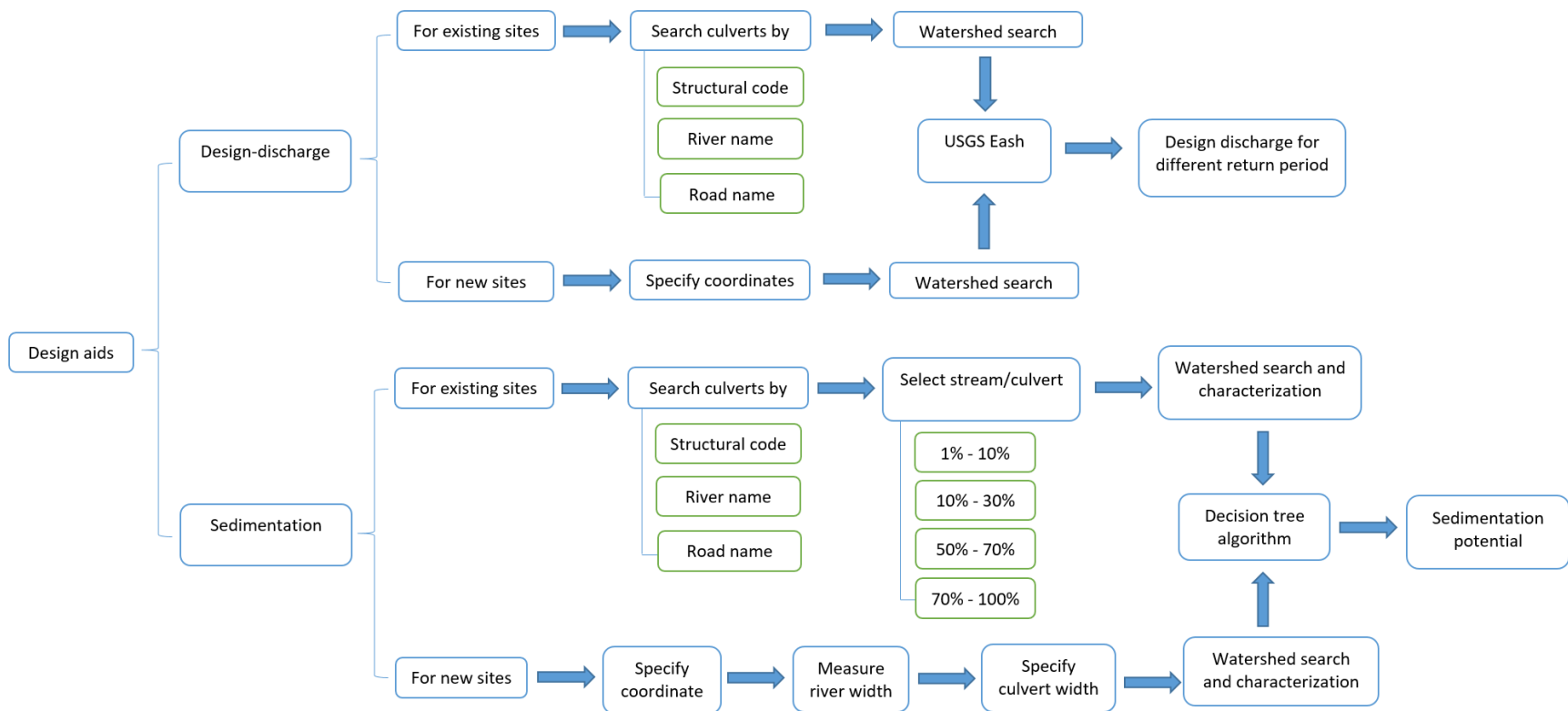
Figure 7. "Decision Aids" workflow flowchart for evaluating the degreee of sedimentation at an exiting culvert or for infroming the design for the potential of sedimentation at a new culvert site.

3.3.   Transfer phasing

As mentioned above, the conceptual design and the finalized prototype of the Iowa DOT Culverts web tool have been already presented in several state, regional and national dissemination and training events. The most relevant technology transfer activities for the present context are the in-depth technology transfer opportunities made possible through the State Transportation Innovation Councils (STIC) Incentive Funds awarded to this research team in 2016. The STIC Incentive Program enabled a series of workshops organized by the Iowa Institute of Transportation's Local Technical Assistance Program (LTAP) for the dissemination of self-cleaning design and of the prototype web portal. We delivered five workshops at strategically chosen Iowa locations with the participation of the Iowa Department of Transportation, counties, cities, and other public stakeholders. The workshop participants offered positive comments on the usefulness and innovation of the geo-platform in mitigating the sedimentation at culverts.

The aforementioned dissemination activities were conducted using the Culvert tool residing on the IIHR servers. These meetings raise the issue of making this tool available for IDOT culvert design and monitoring personnel on a permanent basis. This transfer project is a natural extension of the prototype development targeting the handling of the concept and developed software to the IDOT specialized personnel. The transfer of the prototype Iowa DOT Culverts web platform entailed the following phasing of activities:

1. Meeting with Technical Advisory Committee for TR-665 and potential users from IDOT personnel for evaluating the workflows contained in the tool
2. Applying modifications resulting from Activity 1
3. Installation of a *Windows/Apache/MySQL/PHP, Python, (and/or) PERL (WAMP)* web stack (WAMP is a set of free, open source applications, combined with Microsoft Windows, which are commonly used in Web server environments).
4. Installation for Geoserver and PostGress and PostGIS (back-end components)
5. Migrate the data files stored in PosGress and PostGIX
6. Migrate the Javascript libraries and JSON datafile
7. Testing of the functional and operational features of the platform and final checkup of the platform functionality (connection with SIIMS and hydraulic design software to be evaluated)
8. Implementation of the observations made in Activity 7
9. Preparation of presentation materials and tutorials to be incorporated on the platform
10. Delivery of training session with groups of potential users

During the initial phases, several meetings and email exchanges between our development team and the Information Technology Division's Office of Highway Support (lead by Matthew Rensch, Director of the office) took place to evaluate the needs and challenges related to the platform transfer. This dialogue extended over several months through quasi-regular meetings. As a results an adjusted configuration of the tool's cyberinfratructure was devised such that the transferred version of the environment is free of databases and software that are not supported on a regular basis. Care was taken in this adjustment process that the final geo-portal cyberinfrastructure be as close as possible to the originally-developed prototype with respect to functions, look and feel. However, adaptations, switching of components and software scripts were applied to the original software components as necessary.   The final components for supporting the tool along with the installation and

troubleshooting instructions are provided in Appendix A of this report. A step-by-step guidance for the use of the tool functionalities are described with snap-shots of the interfaces in Appendix B.

4. CONCLUSIONS

The IDOT Culverts web-GIS tool installed on the IDOT computer support environment makes the relevant data on culvert sedimentation easily accessible by assembling in one place pre- and post-construction data and information, irrespective of their provenance. In addition, the tool connects the culverts with their geo-spatial context by offering hydrological and sediment-related characteristics of the drainage area that outflows at the culvert site. The portal usefully enables four sets of workflows that will allow to efficiently conduct the following activities:

(1) storage and query of culvert location and ancillary information regarding the culvert structural and hydraulic specifications

(2) facilitation of monitoring of sedimentation at culverts using in-situ or remote sensing technologies

(3) analysis of the sedimentation at culverts; and,

(4) support of culvert maintenance or design by forecasting the sedimentation potential for any culvert site

The workflows can be applied to existing or potential culvert sites, therefore assisting both operations and design purposes. User-friendly portal interfaces allow users to prepare a systematic plan for culvert monitoring, and offer means for quantitative assessment of the potential for sediment deposit formation.

The benefits of this geo-portal are multi-faceted. First, the web-portal integrates sources of data that are currently available in various formats and repositories. Most of these data are online so they continue to be updated by specialized agencies following verified and sustainable protocols. By connecting those sources to the Iowa DOT Culverts tool, a new, customized resource will that can a) inform and facilitate on-going culvert related activities (e.g., updates on the status of sedimentation at the level of county or IDOT district for resource planning purposes); b) serve as a living repository that can be mined to infer aspects of current designs in relationship with the location of the culvert in diverse geographic areas. Second, the software embedded in the tool allow for the exploration of various relationships between a culvert's status and its evolution in time, commensurate with the changes in the watershed (e.g., correlating changes in the landscape due to socio-economic activities with the changes in conveyance capacity of the culverts over time). Lastly, data sources and software will be hosted in a customized web-portal developed with the end user in mind. Therefore, the platform's tools and functions are equipped with user-friendly graphical interfaces that accommodate the needs of engineers without making recourse at other computational resources. The transferred portal usefully complements current culvert design specifications with conceptualized ground-truth information that correlates sedimentation at culverts with their geometry, stream, and watershed characteristics draining to the culvert site, irrespective of its location in the state.

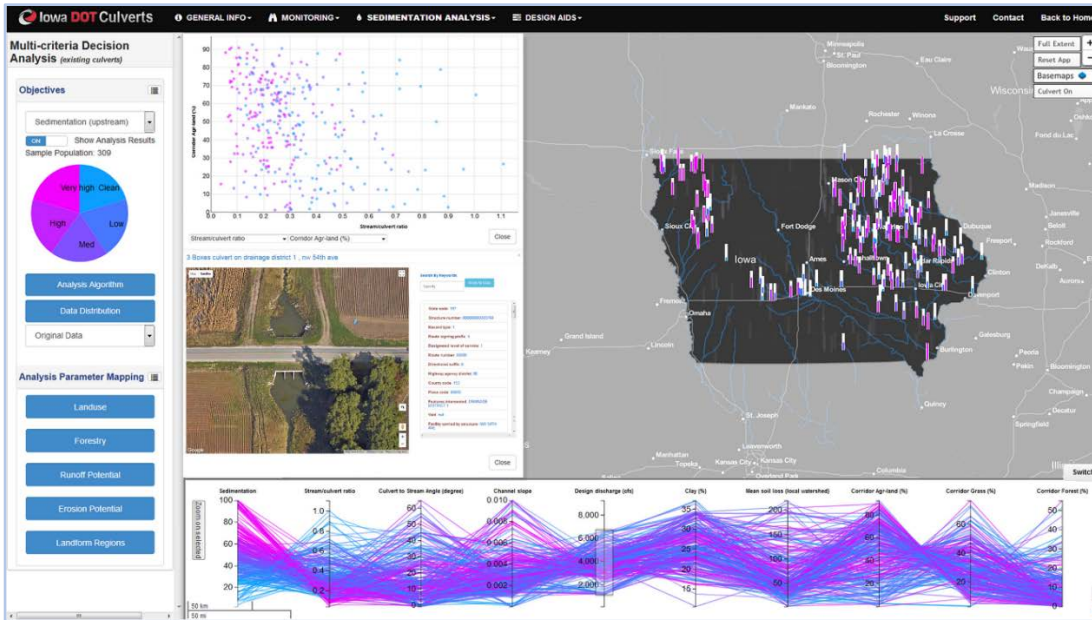Information Technology Division, Office of Highway Support technical personnel including: D. Anderson, R. Parker, K. Perkins, N. Salisbury, M. Nel, D. Brown, and E. Abrams. The continuous support and advice received from all the above offices and colleagues are gratefully acknowledged.

5. REFERENCES

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Appendix A: Platform Installation and Troubleshooting

The Iowa DOT Culverts Platform

Version 1.0

Table of Contents

Acknowledgments

Terms of Use

The data provided through this web platform is intended for scientific and academic research purposes only. Neither the University of Iowa nor IIHR - Hydroscience & Engineering give any guarantees on the absolute accuracy or completeness of the platform's data and functionalities for any commercial usages.

Browser Compatibility:

A1. Product Introduction

Sedimentation is one of the major operational hazards for culverts located in Midwestern areas of the United States. Currently, there are no systematic efforts for mitigating detrimental effects of sediment blockage at culverts, as the problem involves complex and interlinked environmental processes that are difficult to investigate and solve with conventional approaches (e.g., experimental methods and physical modeling). IIHR – Hydroscience & Engineering has developed an innovative web-based geospatial platform, labeled as the "Iowa DOT Culverts" platform, for addressing culvert sedimentation using a data-driven approach. This approach enables identification of culvert sedimentation drivers and quantifies the relationships between drivers and culvert sedimentation severity, making use of an extensive set of multi-disciplinary data. Through user-friendly interfaces and interactive visualizations, the platform facilitates the analysis and forecasting of the sedimentation degree at multi-box culverts across Iowa. Specifically, the platform allows users to: (a) integrate, access, store, and manage diverse culvert-related information; (b) organize and document culvert inspections in real-time; (c) conduct sedimentation-related analyses using visual analytical approaches; and (d) support forecasting of the culvert sedimentation potential. The platform is developed with open-source web technologies and modular system design, making it scalable, flexible, and extendable to other geographical regions.

This documentation presents the overall installation instruction, the file/data description, and troubleshooting guides of the "Iowa DOT Culverts" platform.

A2. Product Installation

The code base and all essential data of the "Iowa DOT Culverts" platform are stored in a file-based system, namely the "root" folder. The installation of the "Iowa DOT Culverts" platform only requires an IIS Web Server (Version 10.0). Currently, all of the platform's codes are written plain JavaScript and HTML, and the platform-associated data is stored in a file-based system (as JSON and CSV files) within the "root" folder. In this setting, there are no additional requirements for server-side applications (e.g., PHP, Python, NodeJS, database, and GIS map servers) for deploying the platform on a web server. All the required third-party JavaScript libraries are downloaded and stored locally within the "root" folder. The total size of the "root" folder is 2.7 GB (without culvert inspection data), and 3.75 GB (with the culvert inspection data).

To install the platform, simply place the "root" folder under the "Default Web Site" directory that is specified through the IIS Web Servers, and then start the IIS service (as shown in Figure A.1).
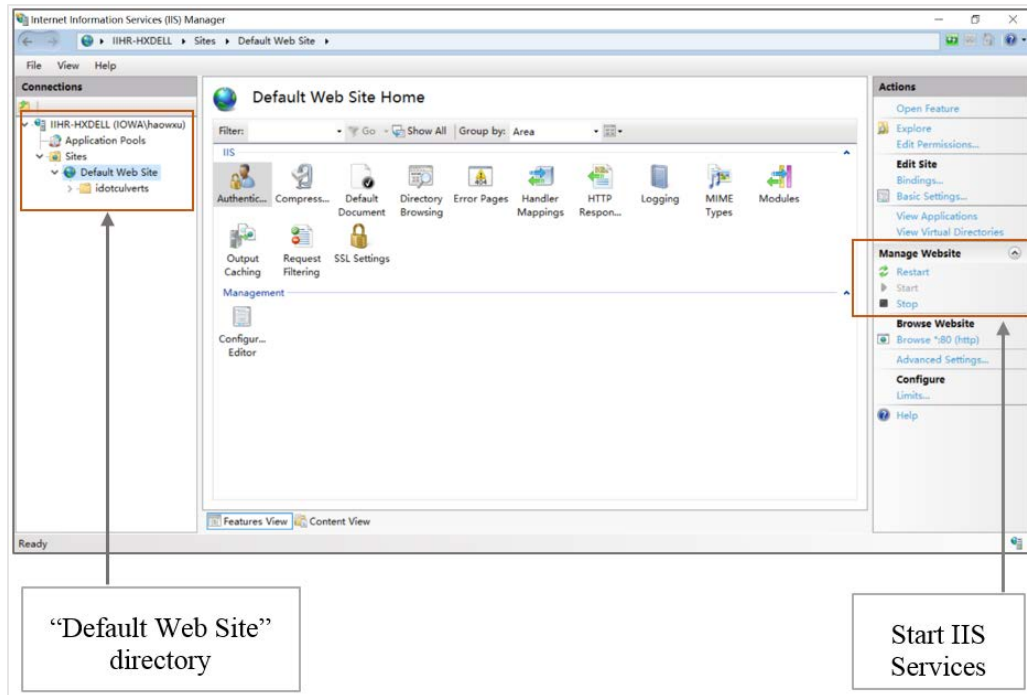
Figure A.1 IIS server configuration.

On small instances, server load is primarily driven by peak visitors, so minimum system requirements are difficult to judge. Here is the minimum hardware recommendation:

- **CPU:** Quad core 2GHz+ CPU
- **RAM:** 16GB
- **Minimum database space:** 10GB

A3. Structure of the "Root" Folder

The "Iowa DOT Culverts" platform includes two major components: (1) platform landing page and (2) main application (main app). The code base of the "platform landing page" is stored in the "root" folder (Figure A.2), and the code base of the "main application" is contained in the "IowaWS" folder (Figure A.3) that is placed under the "root" folder.

The tree-structure of the "root" folder:

Filename	Size
▲ 📁 assets	--
▲ 📁 css	--
⚙ app.css	16.5 KiB
⚙ bootstrap3.3.7.min.css	118.4 KiB
▲ 📁 img	--
▷ 📁 logos	--
▷ 📁 photo_slide	--
▲ 📁 js	--
📜 app.js	11.2 KiB
📜 Bootstrapv3.3.7.js	36.2 KiB
📜 jQueryv3.2.1.js	84.6 KiB
🌐 culvert_tutorial_no_header.html	5.7 KiB
🌐 culvert_tutorial.html	7.4 KiB
▲ 📁 data	--
📕 idot_culvert_portal.pdf	2.5 MiB
▷ 📁 pdf_img	--
📕 sedim_problem.pdf	6.9 MiB
📕 solutions.pdf	12.2 MiB
▲ 📁 tutorial	--
🖼 design_aids.png	638.9 KiB
📕 documentation.pdf	3.8 MiB
🖼 general_info.png	1.3 MiB
🖼 introduction_page.png	555.9 KiB
🖼 monitoring.png	1.3 MiB
🖼 sediment_analysis.png	483.3 KiB
🖼 user_manual.png	81.2 KiB
▷ 📁 video	--
📕 workshop_flyer.pdf	60.3 MiB
📕 workshop_outline.pdf	985.0 KiB
🌐 index.html	12.4 KiB
▷ 📁 IowaWS	--

Landing page assets:

(1) Landing page photo slides (PNG images) and logos
(2) Landing page JavaScript and CSS files

← Landing page-level tutorial that is embedded as an iframe
← Landing page-level tutorial (independent HTML

Landing page data:

(1) tutorial videos
(2) pdf lectures
(3) pdf slides as images
(4) tutorial thumbnails

←   Index
←   "Main app" folder

Figure A.2 Directory of the root folder.

A4. Structure of the "Main App" Folder

The tree-structure of the "main app" folder:

Filename	Size	
▲ 📁 assets	--	Main application assets
▷ 📁 css	--	
▷ 📁 img	--	
▷ 📁 js	--	
▲ 📁 culvert_time_series	--	Culvert time-series map viewer:
▷ 📁 assets	--	This is a component of the main
▷ 📁 cfs	--	culvert platform.
📄 cfs_previous_survey.html	9.3 KiB	
▷ 📁 data	--	
📄 index_eagleview.html	1.8 KiB	
📄 index.html	6.5 KiB	
▲ 📁 data	--	Main application data
▷ 📁 culvert_watersheds	--	
▷ 📁 dss	--	
▷ 📁 dss_tool	--	
▷ 📁 ifis_search	--	
▷ 📁 state_data	--	
📄 index.html	11.6 KiB	← Main culvert platform html

Figure A.3 Directory of the mina application folder.

The above figures illustrate the overall file structures within the "root" (landing page) and "IowaWS" (main application) folder. During the platform development, we adopted the convention of using "assets" directory to manage and store all the application related JavaScript, CSS, and Image files. The platform data is stored through a file-based system placed in the "data" folder. There are four user interface levels within the application, as shown in Figure A.4. More detailed inventory/description of the platform assets and data are provided in the table below. Table A.1 – A.3 also specify how each script and data is used within different platform workflows.
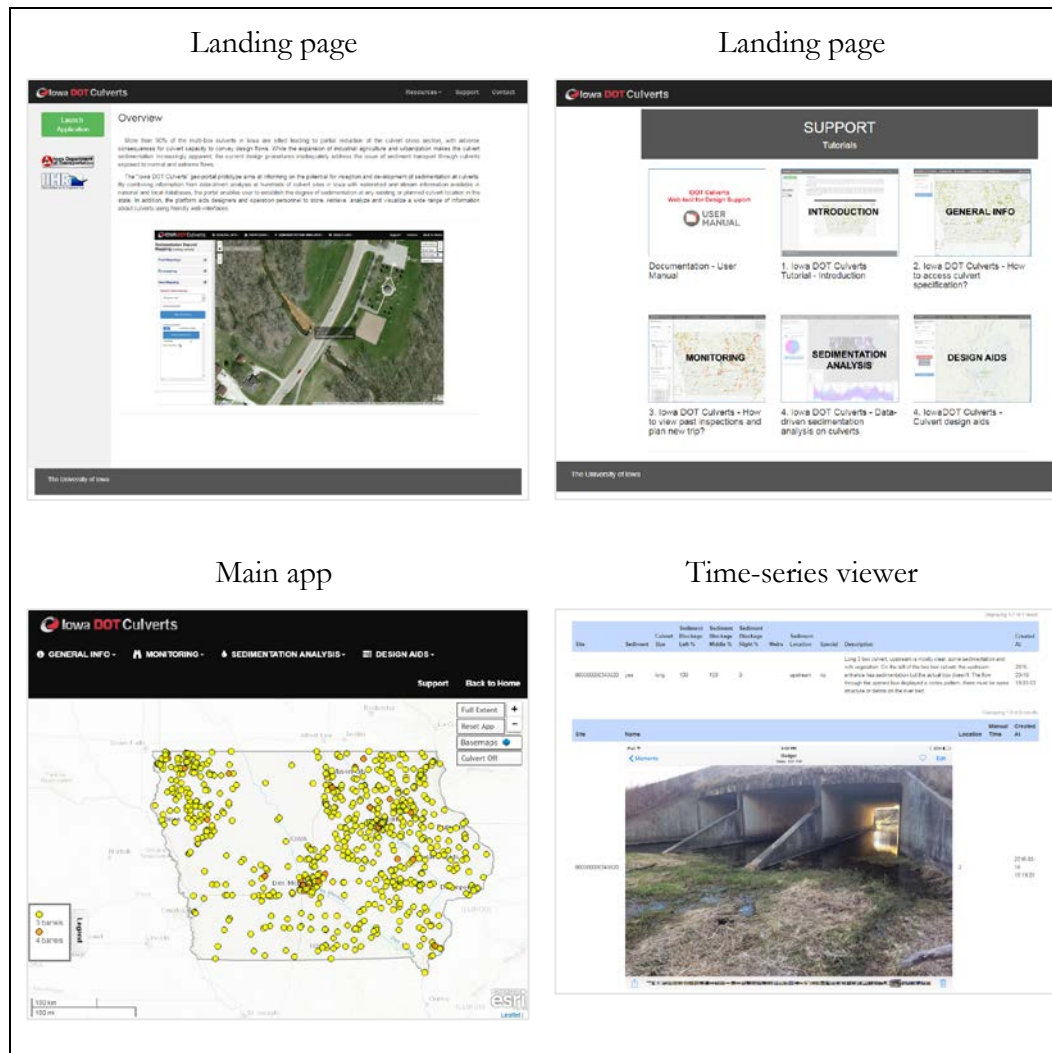
Figure A.4. Different level of the application.

A5. Inventory of Scripts and Data

Table A.1 List of HTML files.

HTML Name	Application	Description
index.html	landing page	The HTML file for the landing page
culvert_tutorial.html	landing page	The HTML file for the tutorial page
culvert_tutorial_no_header.html	landing page	The tutorial page HTML embedded in the main app
IowaWS/index.html	main app	HTML page for the main application
IowaWS/culvert_time_series/index.html	time-series viewer	Culvert time-series image viewer embedded in the main app
IowaWS/culvert_time_series/cfs_previous_survey.html	time-series viewer	Past culvert inspection viewer embedded in the main app

Table A.2 Data inventory.

Data Folder	Application	Data Types	Description
IowaWS/data/culvert_watersheds/culvert_nhd_ws	main app	GeoJSON	This data directory stores culvert upstream watersheds boundaries (created based on the NHD)
IowaWS/data/culvert_watersheds/ifis_watersheds	main app	GeoJSON	This data directory stores culvert upstream watersheds boundaries (created based on the IFIS watershed search engine)
IowaWS/culvert_time_series/ data	main app	JSON and PNG	This data directory stores culvert past inspection images and notes
IowaWS/data/dss/IDOT/img	main app	PNG	Stores Iowa DOT logos (for the navigation bar)
IowaWS/data/dss/IDOT/NHD/grid_to_catchment	main app	JSON	Information that connects geographic coordinates in Iowa with NHD catchment id (essential for the "sedimentation potential warning" tool)
IowaWS/data/dss/IDOT/NHD/grid_to_catchment_character	main app	JSON	Information that characterizes NHD catchment (essential for watershed characterization in the "sedimentation potential warning" tool)
IowaWS/data/dss/IDOT/state_data/	main app	PNG	PNG image that represents flow directions at culverts

direction_lable_s			
IowaWS/data/dss/IDOT/state_data/ geo_json	main app	GeoJSON	Contains state-wide geo-spatial information (e.g., state boundary, culverts, and road network)
IowaWS/data/dss_tool/siims	main app	JSON	Stores culvert structural attributes extracted from the SIIMS database
IowaWS/data/dss_tool/streamcat	main app	JSON	Stores culvert upstream watershed attributes extracted from the StreamCat database
IowaWS/data/ifis_search	main app	PNG	Stores flow direction data and Eash hydrologic regions (essential for the "design discharge estimation" tool)
IowaWS/data/state_data	main app	GeoJSON	Stores state boundary and NHD watershed boundary at the entire Iowa scale
data	landing page	PDF	Contains PDF files of "self-cleaning culvert" workshop presentations
data/tutorial	landing page	PNG and PDF	Contains PDF user documentation and thumbnails
data/tutorial/video	landing page	MP4	Contains tutorial videos for different platform workflows
data/pdf_img	landing page	PNG	Contains PNG that represent PDF presentation slides

Table A.3 Inventory of JavaScripts.

JavaScript_Name	Application	Comment	Description
assets/js/app.js	landing page	Included	JavaScript that animates the landing page and tutorial page
assets/js/jQueryv3.2.1.js	third-party	N/A	JavaScript that is essential for the entire platform, simplify HTML DOM tree traversal and manipulation
assets/js/Bootstrapv3.3.7.js	third-party	N/A	JavaScript and CSS-based design templates for GUI design
IowaWS/assets/js/map_setup.js	main app	Included	JavaScript that is responsible for setting up the Leaflet map
IowaWS/assets/js/dss_app/idot_setup.js	main app	Included	JavaScript that is responsible for the entire apps (e.g., controlling data import, workflows, GUI generation, and map displays)
IowaWS/assets/js/dss_app/birdeye_view_setup.js	main app	Included	JavaScript that is responsible for the culvert "bird-eye viewer"
IowaWS/assets/js/dss_app/discharge_predict.js	main app	Included	JavaScript that is responsible for the "design discharge estimation" tool
IowaWS/assets/js/dss_app/culvert_sed_prediction.js	main app	Included	JavaScript that is responsible for the "sedimentation potential warning" tool
IowaWS/assets/js/dss_app/ifis_watershed.js	main app	Included	JavaScript for searching culvert upstream watersheds (essential for the entire platform)
IowaWS/assets/js/dss_app/culvert_navigation/ Geocoder_control.js	third-party	N/A	JavaScript for providing "geocoding and navigation to culvert" through the Leaflet map (essential for the "field surveys" tool)

IowaWS/assets/js/dss_app/culvert_navigation/ leaflet-routing-machine.min.js	third-party	N/A	JavaScript for providing "navigation to culvert/inspection route planning" through the Leaflet map (essential for the "field surveys" tool)
IowaWS/assets/js/dss_app/culvert_pcp/ survey_correlation.js	main app	Included	JavaScript that is responsible for the "multi-criteria decision analysis" tool
IowaWS/assets/js/dss_app/culvert_pcp/extensions/ survey_nested_mean.js	main app	N/A	JavaScript for improving the PCP visualization (essential for the "multi-criteria decision analysis" tool)
IowaWS/assets/js/leaflet/leaflet.js	third-party	N/A	JavaScript API for Leaflet web map engine
IowaWS/assets/js/leaflet/Leaflet_draw.js	third-party	N/A	JavaScript for allowing users to draw cross-sections on the Leaflet Map (essential for the "sedimentation potential warning" tool)
IowaWS/assets/js/leaflet_extension/ leaflet_google.js	third-party	N/A	JavaScript extension that enables the leaflet map engine to use Google basemap
IowaWS/assets/js/leaflet_extension/ leaflet_geolocator.js	third-party	N/A	JavaScript that enables geocoding for the Leaflet map (essential for the "field surveys" tool)
IowaWS/assets/js/leaflet_extension/leaflet_esri.js	third-party	N/A	JavaScript extension that enables the leaflet map engine to use ESRI basemap
IowaWS/assets/js/leaflet_extension/ leaflet_core_function.js	third-party	N/A	JavaScript library that simplifies leaflet web map operations (essential for the entire platform)
IowaWS/assets/js/leaflet_extension/d3.parcoords.js	third-party	N/A	JavaScript API for Interactive Information Visualization (foundation for the PCP)

IowaWS/assets/js/utility/typehead0.10.5.js	third-party	N/A	JavaScript for enabling autocomplete in the culvert search (essential for the "general info" workflow)
IowaWS/assets/js/utility/simple_statics.js	third-party	N/A	Simple JavaScript for math manipulation (essential for " multi-criteria decision analysis" tool)
IowaWS/assets/js/utility/lists_min.js	third-party	N/A	Simple JavaScript for array/math manipulation (essential for the " multi-criteria decision analysis" tool)
IowaWS/assets/js/utility/jquery2.1.4.js	third-party	N/A	JavaScript that is essential for the entire platform, simplify HTML DOM tree traversal and manipulation
IowaWS/assets/js/utility/jquery_double_scoll.js	third-party	N/A	JavaScript for generating double scroll bar (essential for the " multi-criteria decision analysis" tool)
IowaWS/assets/js/utility/jquery-ui1.11.3.js	third-party	N/A	JavaScript extension for JQuery user interface design
IowaWS/assets/js/utility/decision_tree.js	third-party	N/A	JavaScript for generating decision trees (essential for the "sedimentation potential warning" tool)
IowaWS/assets/js/utility/d3js_3.5.6.js	third-party	N/A	JavaScript API for Interactive Information Visualization(e.g., PCP) (essential for the "multicriteria decision analysis" tool)
IowaWS/assets/js/utility/bootstrap_switch3.3.2.js	third-party	N/A	JavaScript that enables Bootstrap-style switch (part of GUI)
IowaWS/assets/js/utility/bootstrap_3.2.0.js	third-party	N/A	JavaScript and CSS-based design templates for GUI design

IowaWS/culvert_time_series/assets/js/app.js	time-series viewer	Included	Main javaScript that is responsible for controlling culvert time-series image viewer
IowaWS/culvert_time_series/assets/js/bootstrap.min.js	third-party	N/A	JavaScript and CSS-based design templates for GUI design
IowaWS/culvert_time_series/assets/js/leaflet_google.js	third-party	N/A	JavaScript extension that enables the leaflet map engine to use Google basemap
IowaWS/culvert_time_series/assets/js/leaflet.js	third-party	N/A	JavaScript API for Leaflet web map engine

A6. Trouble Shooting

6.1 Error # 1

Problem	Google basemap stopped working in the leaflet map engine.
Cause	Google Map API Key Expires.
Solution	Update the API key in the google map API script link in "IowaWS/index.html" and "IowaWS/culvert_time_series/index.html".

6.2 Error # 2

Problem	Leaflet basemap link expired.
Cause	The link of leaflet WMS layer expired.
Solution	Update the WMS link of the expired basemap in "IowaWS/assets/js/map_setup.js".

6.3 Error # 3

Problem	Routing tool failure.
Cause	The link of "leaflet routing machine" expired.
Solution	Update the codes of "leaflet geocoder" and "leaflet routing machine" in "IowaWS/assets/js/map_setup.js".

6.4 Error # 4

Problem	Time-series viewer images not loaded.
Cause	The web loading speed is slow to load maps from Iowa Geographic Map Server.
Solution	Update both the link of the web map services in the script: "IowaWS/ culvert_time_series/assets/js/app.js", as well as the template in the HTML file "IowaWS/culvert_time_series/ index.html".

6.5 Error # 5

Problem	Past culvert inspection data failed to load.
Cause	The past culvert survey information is stored in a file-based system and is not properly connected with the past inspection information viewer.
Solution	Please verify the relative link in the "culvert_trans/IowaWS/culvert_time_series/cfs_previous_survey.html" file.

6.6 Error # 6

Problem	Bootstrap Glyph icons not displaying.
Cause	Bootstrap glyphicons files missing.
Solution	Please download the "glyphicons-halflings-regular.svg" and place it in the "IowaWS/culvert_time_series/assets/fonts" folder.

Appendix B: User Guide

The Iowa DOT Culverts Platform

Version 1.0

Table of Contents

Acknowledgments

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Browser Compatibility:
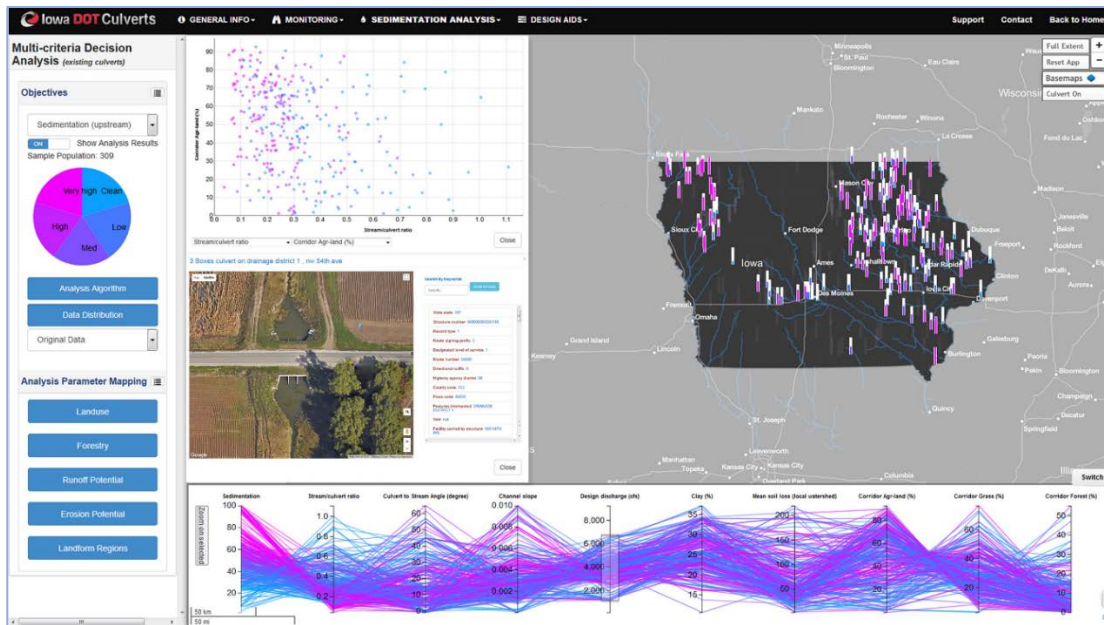
B1. An Overview of the Platform Workflows

The "Iowa DOT Culverts" geospatial platform aims at informing users on the potential of sediment deposition at culverts. Through a web environment, the platform provides various tools that allow users to (a) integrate, access, store, and manage diverse culvert-related information, (b) organize and document in real-time culvert inspections, (c) conduct sedimentation-related analyses using computer-driven visual analytical approaches, and (d) support the forecasting of culvert sedimentation potential across Iowa. Besides, the platform also provides friendly web-interfaces (shown in Figure B.1) to help designers and operation personnel store, retrieve, analyze and visualize a wide range of information about culverts using a variety of computer devices.
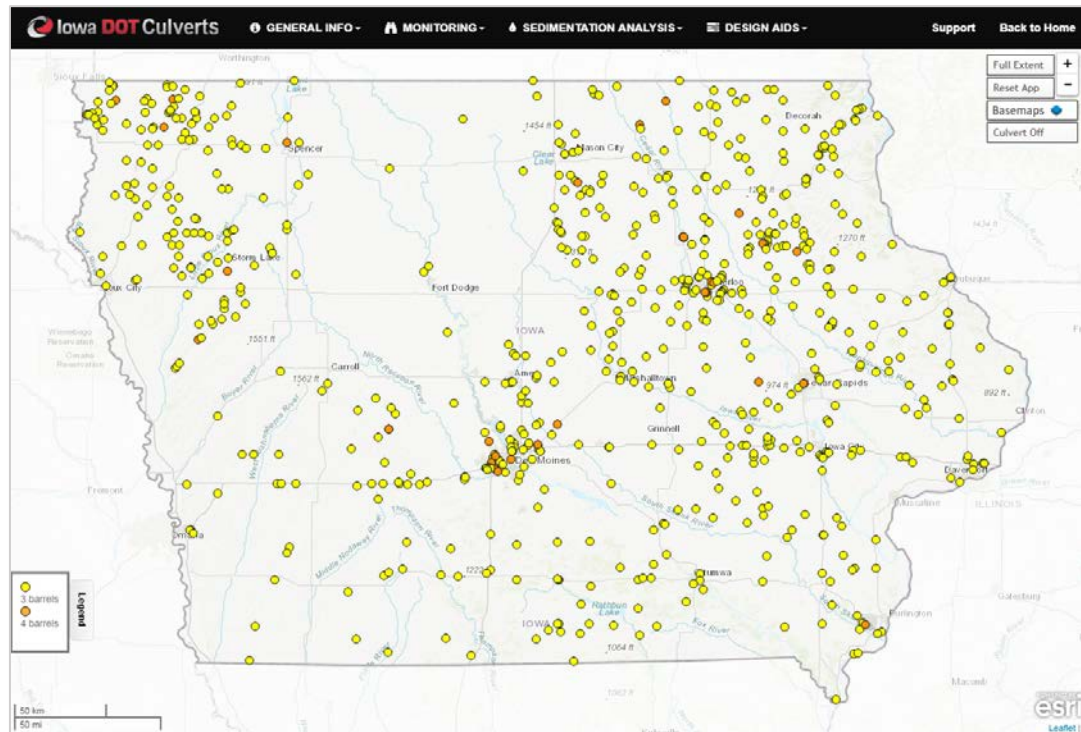
Figure B.1. Overview of the platform interface.

The "Iowa DOT Culverts" contains four major workflows: (1) general info, (2) monitoring, (3) sedimentation analysis, and (4) design aids for promoting culvert info access, inspection, and facility culvert sediment mitigation design through data-driven culvert sedimentation analysis. This user guide offers step-by-step instructions on the usage of different platform workflows (shown in Figure B.2) and their containing tools (summarized in Table B1).

Figure B.2. Workflows of the "Iowa DOT Culverts" platform.

Table. B. 1 Summary of the platform's workflows and their containing features.

Platform Workflows	Platform Features/Tools
GENERAL INFO	"Simple Search"
GENERAL INFO	"Extended Search"
MONITORING	"Field Surveys"
SEDIMENTATION ANALYSIS	"Multi-criteria Decision Analysis"
DESIGN AIDS	"Design-discharge Estimation"
DESIGN AIDS	"Sedimentation Potential Warning"

B2. General Info

The "General Info" workflow is developed to provide users with an easy-accessible repository of culvert inventory information. The workflow contains two tools, providing accurate culvert identification based on different culvert specifications.

B2.1 Simple Search

The "Simple Search" identifies the location of culverts based on three fundamental criteria: (1) river name, (2) road name, and (3) structure codes. The user interface of the "Simple Search" is illustrated in Figure B.3.

In a use-case scenario, a user wants to find a culvert located on the "Spencer Creek" in Iowa. As the user only knows the river name where the culvert is built on, the user can switch "search culverts by" option to the "River Name", and types in "Spencer Creek" (shown in Figure B.4a). The culvert search tool then displays an autocomplete drop-down menu, listing all the culverts that satisfy the user's search criteria. With a click on each item within the drop-down menu, the tool identifies the culvert location and adjusts the map view to display the culvert structure (shown in Figure B.4b). Furthermore, users can click on the culvert location in the web map to activate a culvert info window (shown in Figure B.4c) that displays a bird's-eye view map of the culvert site, as well as detailed culvert structural specifications. Using rotation tools in the bird's-eye view, users can digitally inspect culvert structures from four different directions. Meanwhile, on the right-hand side, detailed culvert structure information (e.g., culvert geometry, site codes, and maintenance information) that is retrieved from the Iowa DOT SIIMS database, is displayed in a searchable list and can be filtered using keywords.
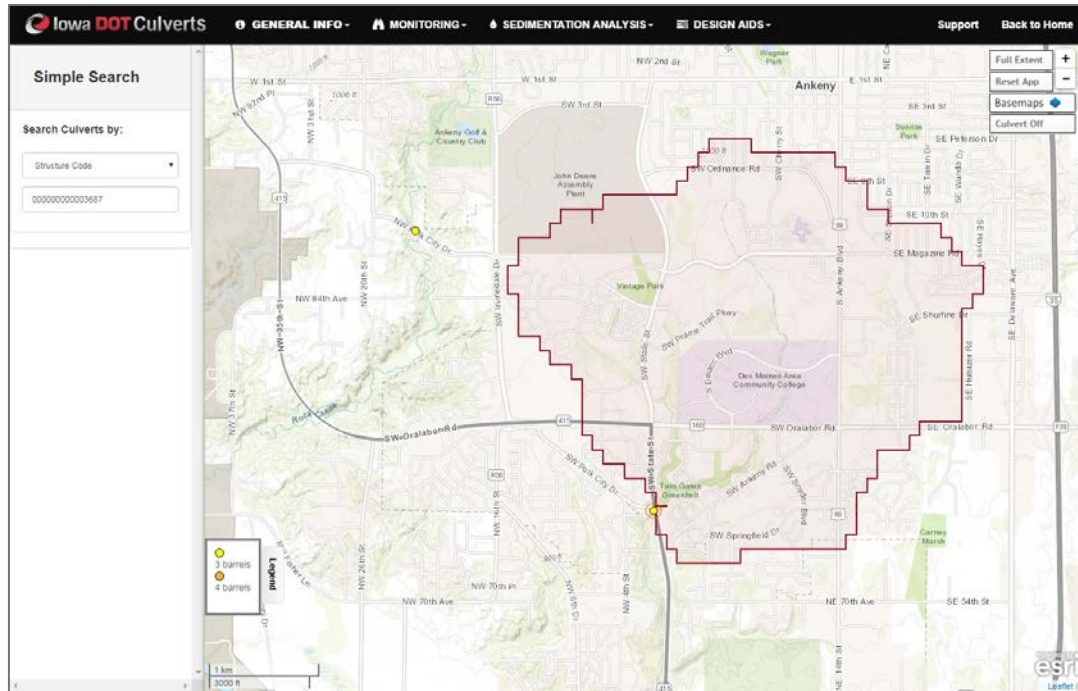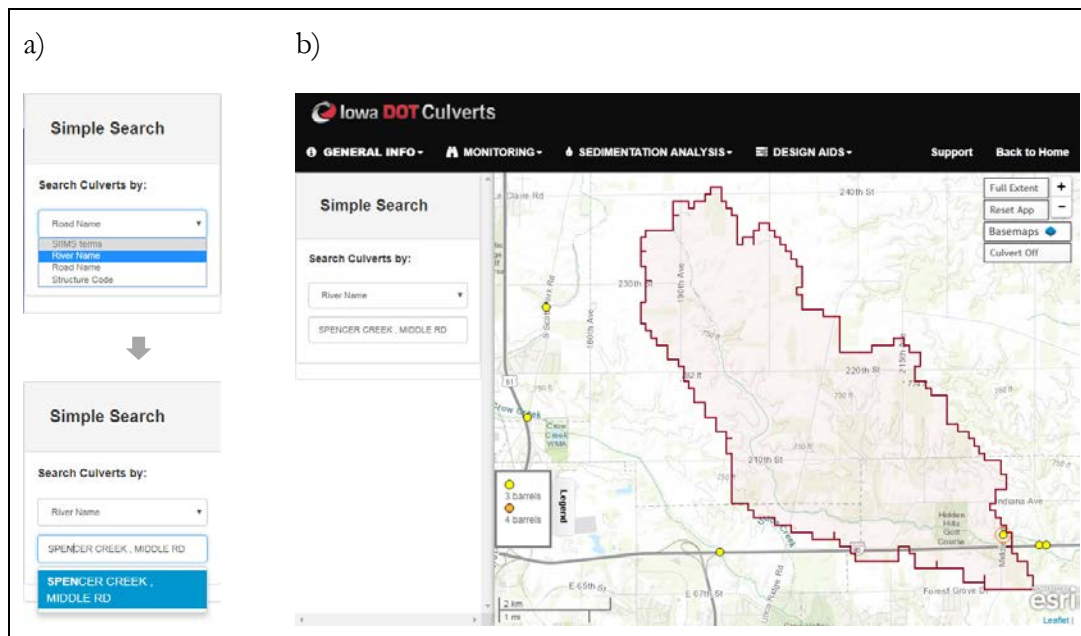
Figure B.3. The user interfaces and web map of the "Simple Search" tool.
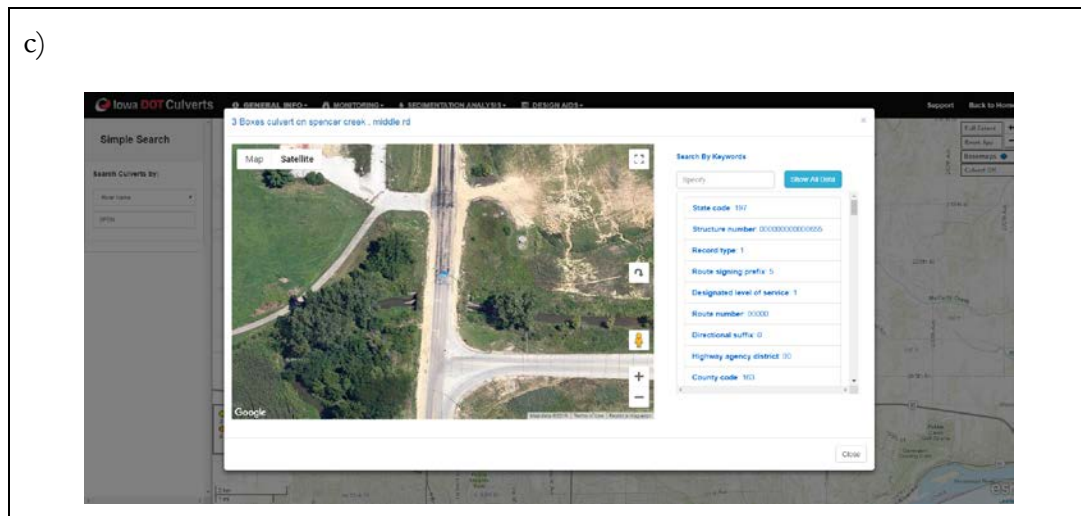
c)

Figure B.4. The "Simple Search" user showcase: (a) search a culvert by river name, (b) map zooms to the identified culvert, and (c) culvert info window.

B2.2 Extended Search

The "Extended Search" provides users with capabilities to filter culverts by additional attributes, such as the number of boxes, types of self-cleaning design, and other instrumentations. By clicking the "Show All Culverts" button, the user is able to restore the default view of the culvert map. In a use-case scenario, users can filter culverts with specific attributes and display their locations through the map (as illustrated in Figure B.5a). Figure B.5b presents an example when the user wants to show all the culverts that have 4 barrels on the map. Additionally, the user also has the capability to view culvert sites with self-cleaning designs (e.g. filet-based, downstream weir, and upstream curtain).

a)   a)
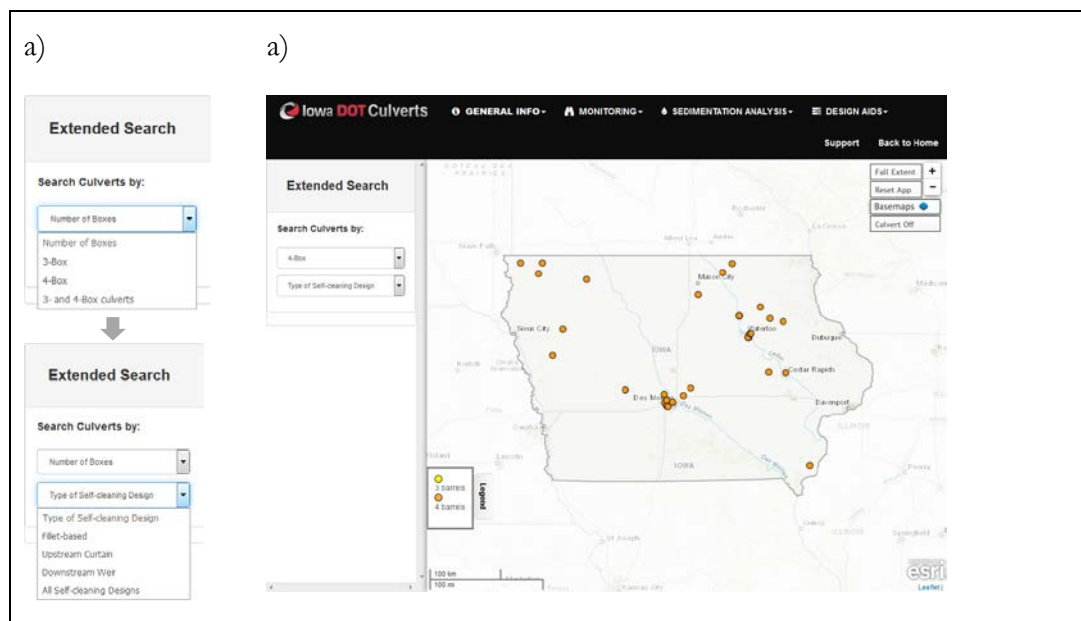
Figure B.5. The "Extended Search" user showcase: (a) filter culverts by attributes and

(b) displaying culverts with 4 boxes.

B3. Monitoring

The "Monitoring" workflow provides tools to retrieve past survey info (data & routes) and plan new survey trip (navigation, field data uploader, routes planning). The workflow contains a "Field Surveys" tool with three functional tabs: (1) search culverts, (2) past survey routes, and (3) plan new survey routing. Since this tool is designed for supporting the planning of culvert field inspections and real-time data collection, it can be accessed through a variety of mobile devices (e.g., tablets, smart phones, and hotspot) in the field. Detailed interfaces under these tabs are presented in Figure B.6.
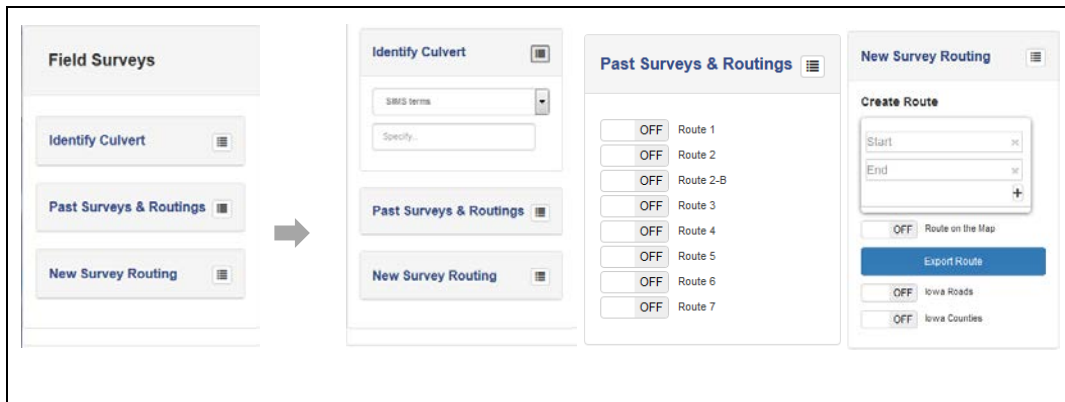
Figure B.6. User interface of three functional tabs within the "Field Surveys" tool.

"Search Culvert" tab provides an easy way to search for culvert locations based on culvert specifications such as road name, river name, and structure code. The tab is similar to "Simple Search" in "General Info" to locate specific culvert, with extended field trip assistance workflows (displayed in a pop-up menu when a culvert location is clicked by the user) that enables (1) see previous inspection(s), (3) navigate to sites, and (4) culvert time-series map, as illustrated in Figure B.7.

In a user case scenario, a user locates the specific culvert of interest by searching structure code "000000000025731" in the "Search Culvert" tab. After locating the culvert site, the user can access past culvert inspection data conducted by IIHR - Hydroscience & Engineering by clicking "see previous inspection(s)" button. The culvert survey info page contains both survey notes and survey images acquired from previous culvert inspection (shown in Figure B.8a). The "Past Survey Routes" tab displays the overall progress of past culvert sediment survey conducted by IIHR - Hydroscience & Engineering. Within the tab, the switch "[OFF] In-situ Surveys " visualizes locations of inspected culverts, which is color-coded in "○". Users can view past survey routes by clicking on different the route switch (e.g. route 1, route 2). Past routes are displayed in colored lines on map (shown in Figure B.8c).

The "New Survey Routing" tab assists the planning of culvert inspection trips in surveyed areas by providing tools for address search, route planning, and weather forecast. The "Create Route" tool allows users to establish routing between specified

addresses. In a user case scenario, a user can plan a trip from Iowa City to Ames by entering two addresses in the "Start" and "End" search boxes. Additional waypoints can be added by clicking the "+" button. If the address is not known, users can specify their destination by simply enabling the switch " OFF Route on the Map " and clicking on the map. After specifying "Start" and "End" address, a route is generated with detailed driving directions and time estimations on the map. Routes can be edited interactively through the map by dragging to find alternative routes and clicking to add waypoints (as shown in Figure B.9a). Users can either export their routes in JSON formats or to other applications (QGIS, Google Earth) by clicking on "Export Route", or send their planned routes to "Past Survey Routes" by clicking on "Post Route". Figure B.9b provides an example of creating a route for a culvert survey trip from Iowa City to Ames.
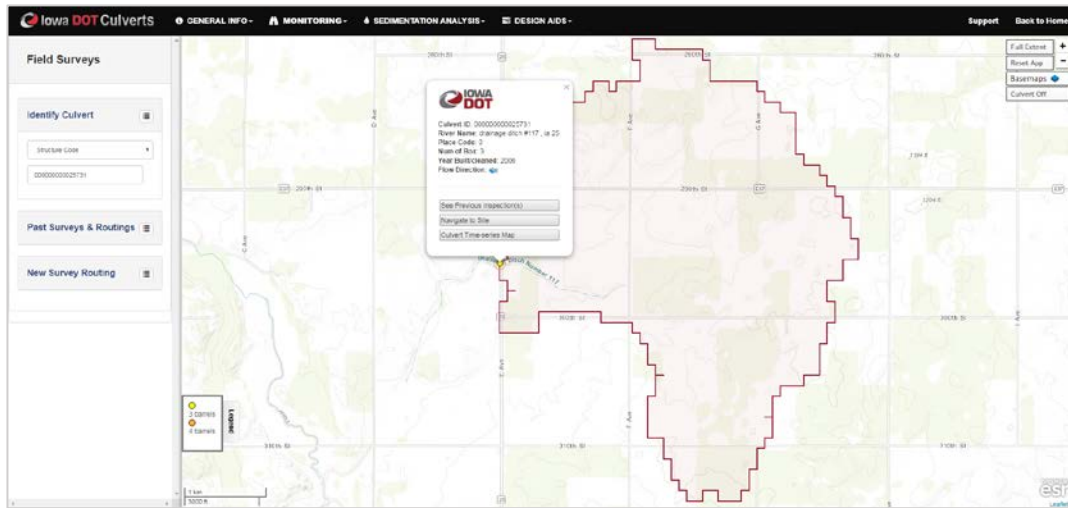
Figure B.7. Extended field trip assistance workflows within the "Field Surveys" tool.

c)
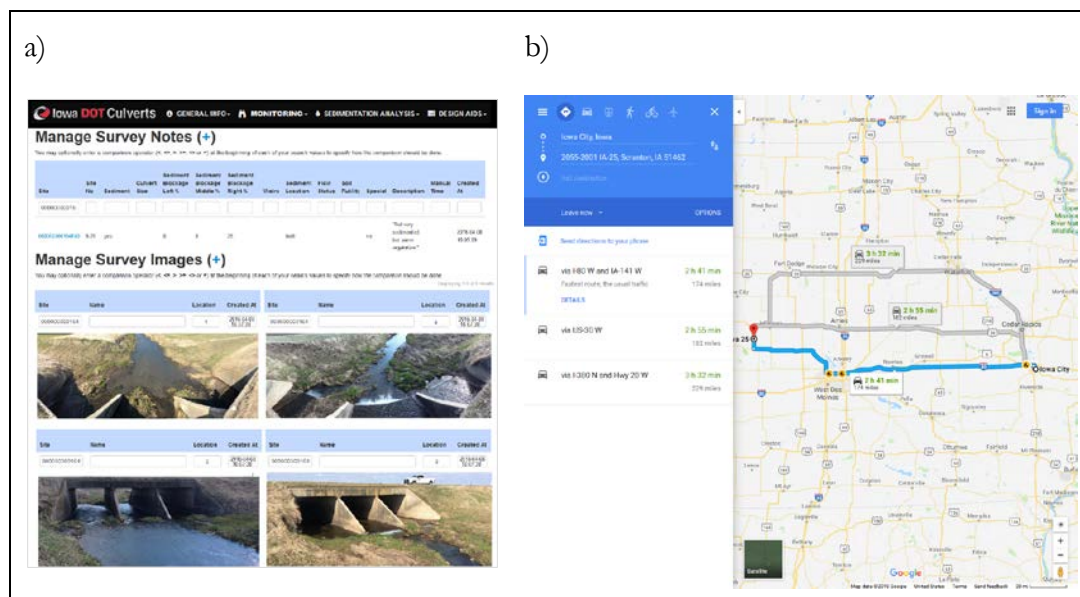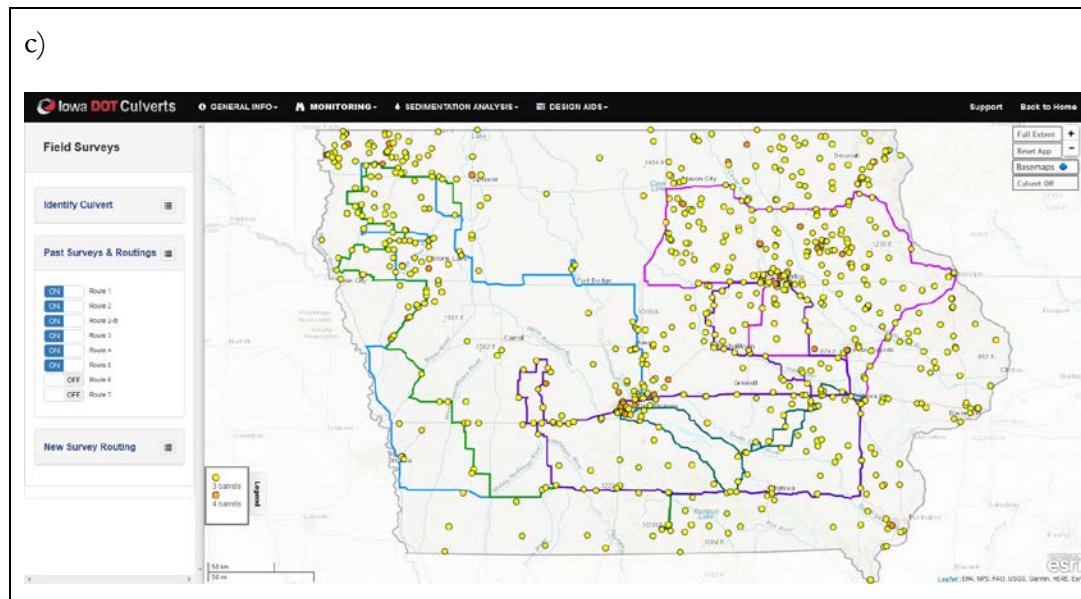
Figure B.8. Extended field trip assistance workflows within the "Field Surveys" tool: (a) past culvert inspection, (b) google navigation to culvert location, and (c) past culvert inspection routes.

a)   b)
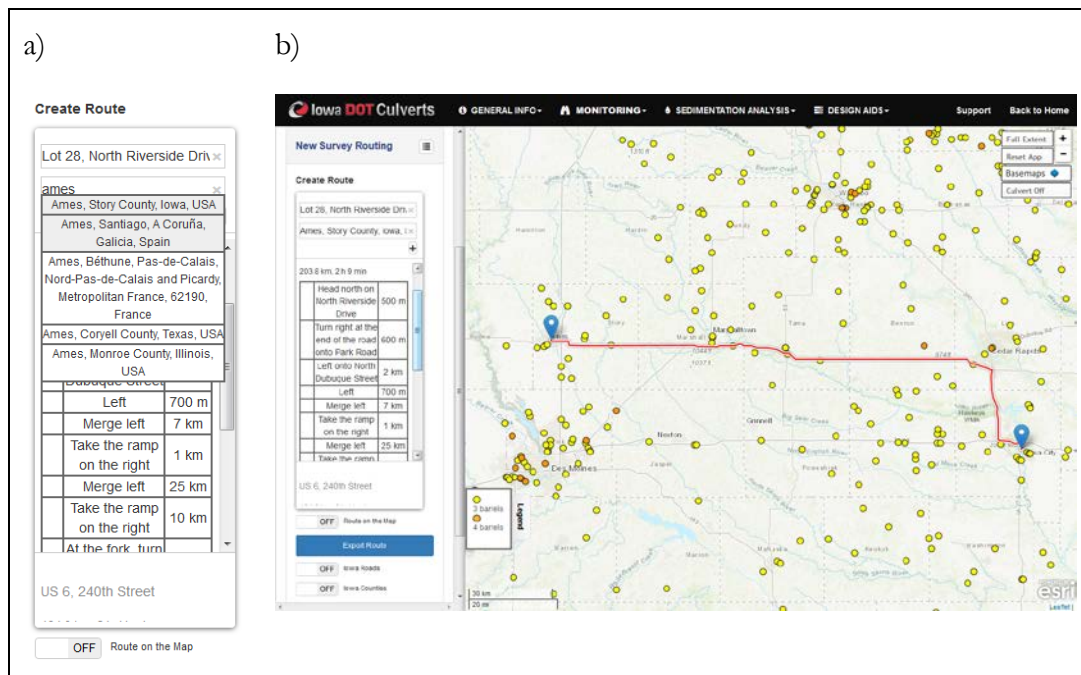
Figure B.9. The user interface of the "New Survey Routing" tab: (a) create routes and (b) displaying results, a route identified from Iowa City to Ames.

B4. Sedimentation Analysis

This workflow provides sedimentation analysis using a data-driven approach. The primary tool under this workflow is the "Multi-criteria Decision Analysis" workflow. The workflow aims at exploring important culvert sedimentation drivers that contribute to culvert sedimentation in culvert upstream drainage areas. The tool utilizes a visual-analytics approach to help users understand the empirical relationships between culvert sediment degrees and key culvert sedimentation drivers, which include culvert structural attributes (e.g. culvert width and design discharge) and upstream watershed characteristics (e.g. channel slope, mean soil loss), through a parallel coordinate plot that is integrated with a machine learning algorithm, the decision tree. The tool is interactive and user-friendly, so that users can play with the tool to get a sense of how different factors affect culvert sedimentation. To conduct an analysis, the user needs to follow the following steps: (1) define sediment criteria in objectives via the dropdown menu, as presented in Figure B.10a, and (2) enable the interactive information visualization (parallel coordinate plots) using the switch " ", shown in Figure B.10b.
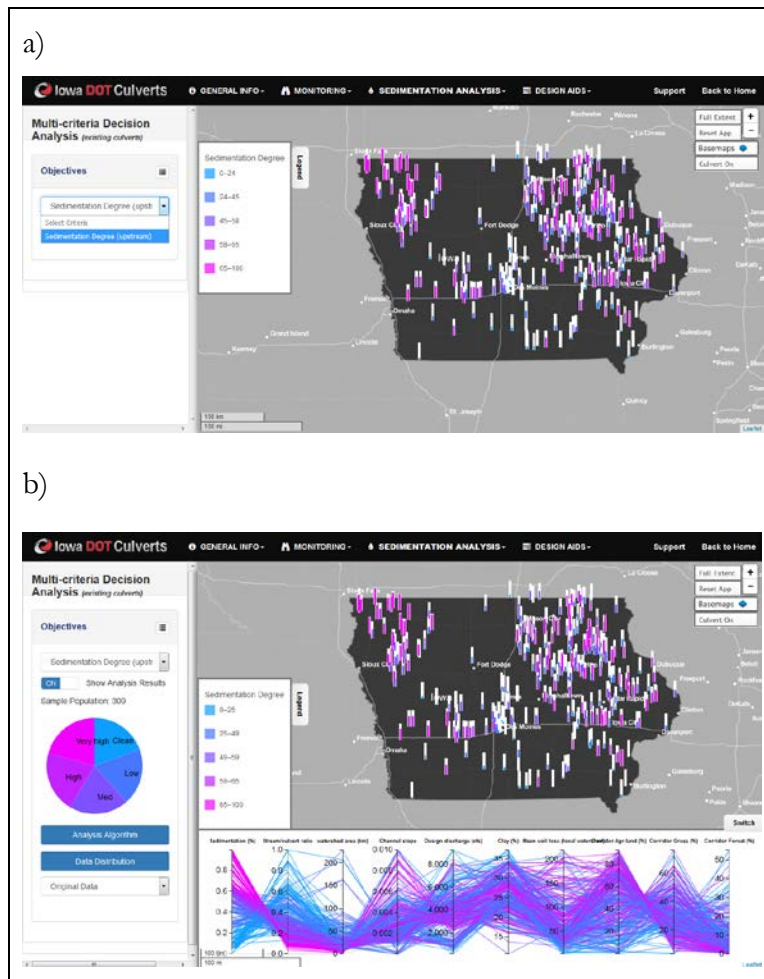
Figure B.10. The visual interface of "Multi-criteria Decision Analysis" tool: (a) create routes and (b) displaying results, a route identified from Iowa City to Ames.

The Parallel Coordinate Plot (PCP) is connected with the web map and provides dynamic data "brushing" capabilities that allow users to filter or select data records, certain ranges and attributes. The PCP is also synchronized other visualizations, including a pie chart for displaying major sedimentation classes (shown in Figure B.11a) and a web map that displays culvert locations with their associated degrees of sedimentation (shown in Figure B.11b). These plots also allow users to interact with the data through filtering and brushing (shown in Figure B.11c), through which users can define criterion to filter data and explore the dependency and culverts' geographic distribution within the data subset (e.g., culverts are located on steep slopes).

To create a brushing range, simply click and drag on each parameter axis. In addition to the visually explicit variability revealed from the parallel coordinate plots, users can also view quantification of the MCDA by clicking "Analysis Algorithm" button, which enables a decision tree that visualizes the sediment relationship. A detailed user case scenario is provided below. A small bunch of decision tree with only two sediment class (med and high) and few parameters (e.g. discharge, grass, and clay) is shown in the figure as an example.
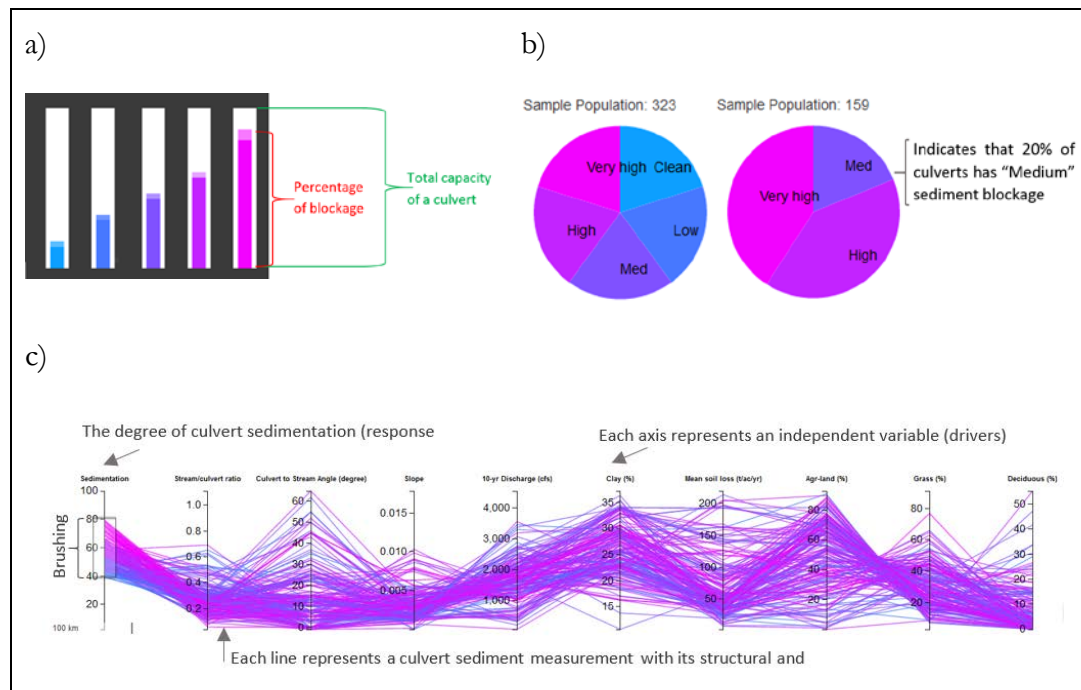
Figure B.11. Visual interface components: (a) bar graph for culvert sediment, (b) pie chart for sediment degree distribution, and (c) elements in the parallel coordinate plot.

B5. Design Aids

The "Design Aids" workflow uses analytical results from the MCDA conducted in previous workflow (Sedimentation Analysis) to support culvert design and retrofitting for mitigating sedimentation. The workflow contains three design-aids tools: (1) Design-discharge Estimation and (2) Hydraulics Design Data.

B5.1 Design-discharge Estimation

Culvert design discharge is a very important parameter that determines the opening of culvert structure. The "Design-discharge Estimation" calculates river discharge for multiple return periods (e.g. 5 year, 10 year, 50 year) using flood probability methods (e.g. USGS Lara method). The tool is designed to estimate design discharge for both (1) Existing Sites and (2) New Sites, as illustrated in Figure B.12.

To estimate discharge for existing sites, click " ON Existing Sites " to enable the estimation interface (as shown in Figure B.13a). The procedure is very similar to culvert search that the user needs to specify a culvert location by structural code. Afterwards, the portal traces the upstream drainage area and reports the result in the sidebar. To estimate discharge for a new site, the user needs to click " ON New Sites "to trigger the new site interface (as shown in Figure B.13b). When the interface is loaded, follow the guide and enter the site coordinates (point of interest). The portal automatically zooms to the coordinates and calculates the design discharge.

Figure B.12. The user interface for the "Design-discharge Estimation" tool.
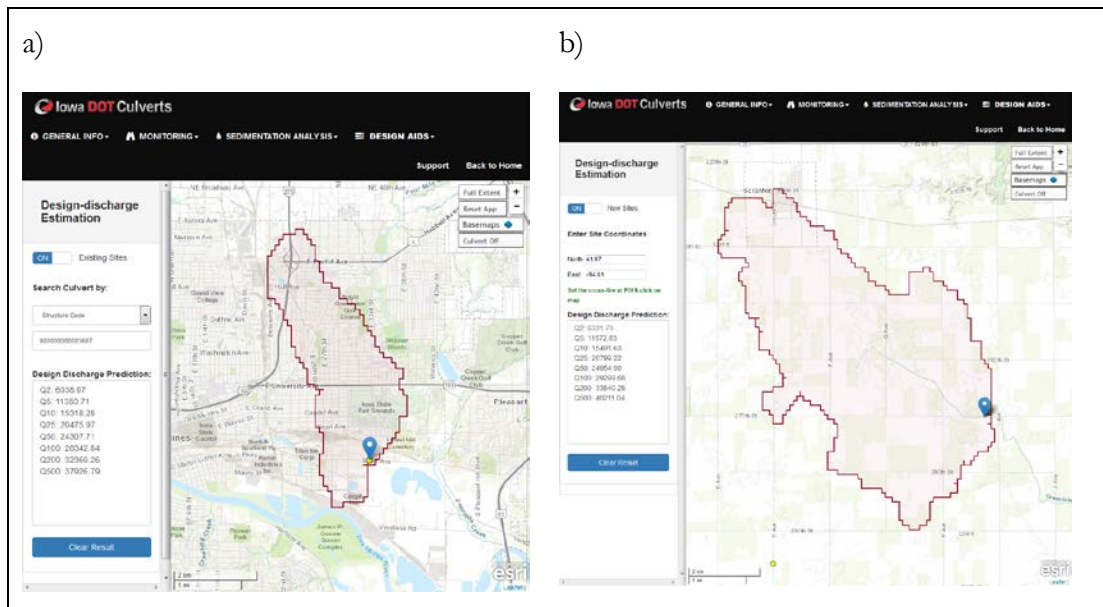
Figure B.13. Estimating design discharge for both (a) Existing Sites and (b) New Sites.

B.5.2 Sedimentation Potential Warning

"Sedimentation Potential Warning" uses a decision tree generated from the previous sediment analysis (Multi-criteria Decision Analysis) to predict sediment potential at both existing sites and new sites. The tool is intended to inform the designer when to apply the "Self-cleaning Design" based on sediment potential while designing new sites. The tool provides predictions for both existing sites and new sites. General user interfaces of this tool are listed below in Figure B.14.

The interface of this tool is very similar to that of discharge estimation (shown in Figure B.15a). To estimate sediment potential for existing sites, click on the switch "[ON] Existing Sites" to activate the corresponding interface. The first step to use this tool is to specify the structural code for estimation, the procedure is the same as discharge estimation. The second step is to define stream/culvert width ratios through the dropdown menu "[1%-10% (oversized)]" as culvert geometry plays an important role in culvert sedimentation. Results of sediment estimation will be provided under the "Degree of sedimentation" section.

To evaluate sediment potential at new sites (shown in Figure B.15b), activate the switch "[ON] New Sites" to display the interface. Steps are as follows: (1) enter coordinates for a new site, (2) delineate river cross-section using "[✎]" tool to measure river width, and (3) specify culvert width using "Culvert Width: [____] (m)" and click "Show Prediction". Afterward, the result of estimation is provided under the "Degree of sedimentation" section. The system using four classes to describe sediment potential at a sites, these classes are described in Figure B.16.

Options for sediment potential estimation	Estimating existing sites	Estimating a new site

Figure B.14. The user interface for the "Design-discharge Estimation" tool.
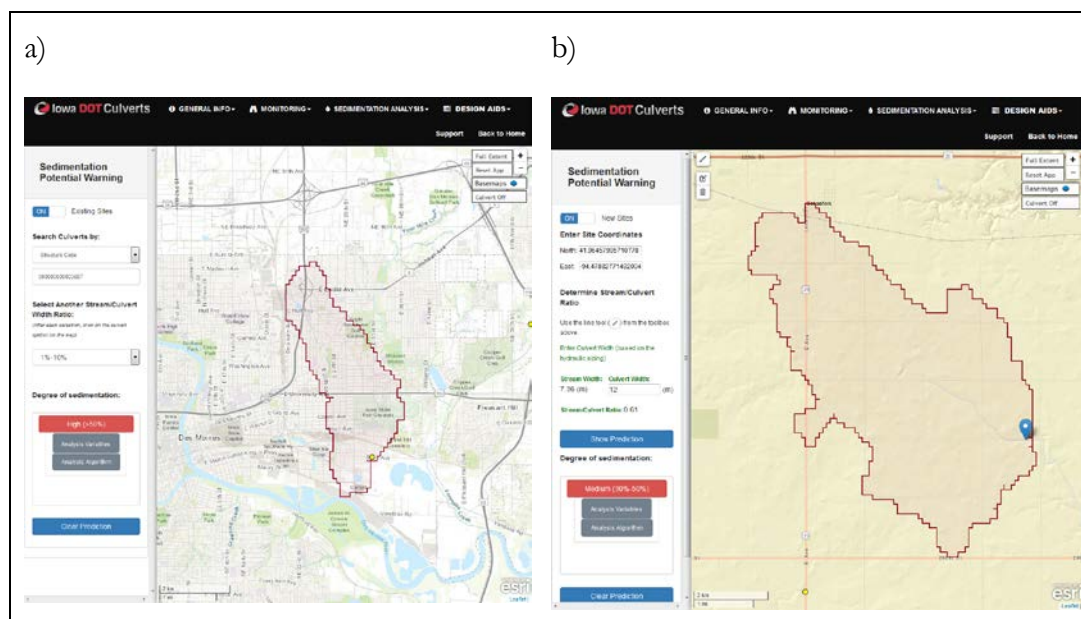
Figure B.15. Estimating culvert sedimentation potential for both (a) Existing Sites and (b) New Sites.

Figure B.16. Classification for sediment potential estimation.