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DRAINAGE INFORMATION ANALYSIS AND MAPPING SYSTEM

FINAL REPORT

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16. Abstract The primary objective of this research is to develop a Drainage Information Analysis and Mapping System (DIAMS), with online inspection data submission, which will comply with the necessary requirements, mandated by both the Governmental Accounting Standards Board (GASB-34) and the federal storm water regulations. The DIAMS project will serve as a vehicle for evaluating underground drainage infrastructure assets which includes locating and cataloging pipes, storm-water devices (e.g., manufactured treatment devices), outfalls, and other structures, (e.g., manholes and catch basins), as well as, collecting inspection and rehabilitation/replacement/repair data. The DIAMS has an electronic documentation system that performs quality checks on the submitted inspection data and stores the approved data in a comprehensive information management system for updating, analysis, classification and mapping. The DIAMS utilizes a two layer front and back end management tool comprised of MS Access for data submission and SQL database for data storage that is accessed through a graphical user interface (GUI). The GUI is structured into four modules: Data Uploading, Asset Identification, System Administration, and Financial Analysis. The Data Uploading module includes the conversion of user input field data into comprehensive information format, review of input data, quality assurance and quality control checking, and appending the data to the system database. Users can locate assets needing immediate repair by road/milepost based upon their condition state. The Asset Identification module stores all the receiving storm water data such as the quality/quantity of water and discharge to watersheds, while also being able to develop general property reports. The module also gives users an assessed condition state, which allows them to select the best treatment technique. The System Administration module allows individual flexibility through editing keywords. The Financial Analysis module analyzes the selected data and provides optimal recommendations to inspect, rehabilitate, replace, repair or do nothing at both project and network levels. Financial analyses are derived from a sequential process including defining networks, confirming input data sets, and optimizing for budget allocation preferences. At the project level this is achieved by comparing inspection and/or rehabilitation/replacement/repair costs via an updatable user cost, currently based on the 2011 NJDOT Engineer's Estimate – Maintenance Drainage Repair Contract, with risks and costs associated with failure. At the network level, the associated costs are optimized to meet annual maintenance budget allocations by prioritizing assets needing inspection and rehabilitation/replacement/repair. When all input data have been appended into the module, DIAMS can generate financial summaries and work orders.

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INTRODUCTION

According to the American Society for Civil Engineers more than 1.6 trillion dollars are needed to update the nation's mostly aging infrastructure through various bonds and public funds. It can be convincingly argued that it would be more cost effective over the long term to spend a good portion of this investment by taking a proactive course in managing the maintenance processes of the infrastructure rather than waiting and being forced to merely react to disruptive incidences. The importance of a proactive maintenance management policy becomes more pronounced when considering vital systems. This importance emanates from the fact that an unexpected failure of a component of one of these complex systems usually creates disruptions, which could have cascading effects leading not only to havoc and its consequences of inconveniencies, but also to major economic effects requiring colossal expenditure to contain the damages incurred from such premature and unexpected failures.

At present, various maintenance treatments are employed by infrastructure agencies to slow deterioration and restore the condition of highway pavements, bridges, culverts and other physical assets. However, budget constraints and other factors have often led to delaying or eliminating the application of these treatments. Such decisions usually have adverse influence on the condition and performance of the particular infrastructure leading to reduced levels of service, faster deterioration rates, and eventually to the need for costly rehabilitation or replacement. Some analytical tools are currently available to address the consequences of delayed application of maintenance treatments for pavements, bridges, pipes and other assets. However, a comprehensive framework for using these tools to demonstrate the potential savings and performance enhancement resulting from applying maintenance treatments at the right time is not readily available. In addition, Phase II of the Governmental Accounting Standards Board, Statement No. 34 (GASB 34) requires public agencies to maintain or improve the overall condition state of their infrastructure systems with annual funding, where the minimum amount needed is provided by a comprehensive asset management system. Hence, the integrated Drainage Identification, Analysis and Mapping System (DIAMS) and subsequent developments should help concerned agencies and asset owners to better assess the benefits of maintenance actions and their role in enhancing the level of service of infrastructure systems. Also, incorporating the expected outcomes of the DIAMS in asset management systems would provide a means for optimizing the allocation of resources.

State DOTs have found that funds made available to maintain infrastructure are insufficient in meeting GASB-34 requirements. Hence the need exists for adopting an optimal strategy that requires accurate information on the present state of infrastructure to be able to predict future performance. The modified approach lays out the requirements towards an efficient drainage infrastructure maintenance and management system. It requires the state DOTs to:

1. Maintain an up-to-date inventory of eligible infrastructure assets.
2. Perform condition assessments of eligible infrastructure assets at least every three years.
3. Summarize the results, noting any factors that may influence trends in the

information
4. Estimate the annual cost of maintenance for infrastructure assets, at or above the established condition level.
5. Ensure that the result of the three most recent condition assessments meet or exceed the established condition level.
6. Compare the estimated maintenance cost of infrastructure assets at or above the established condition level based on amounts spent during each of the past five reporting periods.

To maintain a prescribed level of service within budgetary costs represents substantial expenses for the lifetime of the specific asset. Although it is difficult to make a reliable prediction of structural deterioration and behavior, consequences of delayed application of maintenance treatments play a significant role in the lifetime expenses of the considered infrastructure.

Many experts stand in agreement that a significant portion of the US infrastructure is in the “accelerated damaged” zone. With no serious effort set to rehabilitate our aging infrastructure, this stage of potential deterioration will eventually create the need for colossal investments required to recover them, with increasing risk to the safety of public transportation. The DIAMS was developed to support this disposition and to be a sustainable system with a specific focus on prioritizing maintenance activities subject to operational and budgetary constraints. The following sections describe a proactive data maintenance system.

The need for identifying and mapping drainage infrastructures comes from the fact that transportation agencies develop extensive transportation networks that cross and also drain to natural water bodies. Hence, DOTs are responsible for a large inventory of pipes and other structures. Drainage infrastructure assets often go unnoticed, since they are usually below ground, until a problem arises such as flooding, roadway settlement and even collapse.

A loss of pipe integrity could result in temporary roadway closure and considerable rehabilitation/replacement/repair costs or even worse. In addition, the total collapse of a drainage pipe could pose a major safety risk to motorists, such as the catastrophic failure that occurred on I-88 near Unadilla, NY on June 28, 2006. The New York State Police photograph shown in Figure 1 illustrates the damage to I-88 resulting from a drainage pipe collapse. Two truck drivers were killed when their rigs fell into the washout caused by heavy rainfall. Due to the collapse of I-88 the New York State Thruway (I-90) was closed in both directions from Schenectady to Syracuse. The washout of all four lanes and center median was a result of a failed 30-foot diameter pipe just beyond the Exit 10 interchange. (Albany Times-Union) Failures of this magnitude typically lead to catastrophic accidents, which may involve the loss of life and property. Hence a drainage information analysis and mapping system is necessary for timely maintenance of drainage assets.

Figure 1. Collapse of a Culvert Crossing I-88 on June 28, 2006

Currently, underground infrastructure asset accounting is based on a linear depreciation rate. To ensure long-term durability of pipes, compliance with required federal accounting requirements, state departments of transportation (DOTs) are exploring ways to implement pipe inspection and management programs. This has been a requirement stipulated by the Governmental Accounting Standards Bureau, in the Basic Financial Statements and Management's Discussion and Analysis for State and Local Governments (i.e. GASB-34 Standard, 1999). GASB-34 requires the governing authorities to declare the present worth of infrastructure assets and to provide useful information on maintenance cost and future replacement cost. It also requires reporting of infrastructure assets as a depreciated cost, scheduled based on the historical cost or a discounted replacement cost. In the "GASB-34 Modified Approach" reporting the present cost of preserving eligible infrastructure is allowed in lieu of reporting depreciation or replacement costs.

Many state and local agencies have yet to implement a pipe management plan based on the `Modified GASB Approach'. Collecting and interpreting data in order to assess the present Condition State with respect to deterioration requires accessibility to underground infrastructure, and the ability to perform a proper condition assessment. Hence, the above is a justification for implementing a preventive maintenance program, which incorporates user costs associated with drainage asset failures, such as due to flooding, roadway collapses and ensuing traffic delays and expensive repairs. In many cases indirect costs can easily exceed direct costs, and ignoring them can lead to less than optimal decisions.

The service life of a drainage asset may differ from its design life, and it depends largely on the supporting soil, local environment, and corrosive and abrasive properties of the transported fluid and solids. Recognizing the effects of these factors on the deterioration of pipes and taking actions to maintain the serviceability conditions can prolong service life, which may prevent premature replacement of structures and pipes, and thereby prevent costly failures. There is a widely recognized problem of rehabilitating older, deteriorated pipes and structures throughout New Jersey. NJDOT Maintenance has identified many existing pipes with significant deterioration and section losses at inverts, both alongside and under roadways. These structures pose a great risk factor to transportation systems and users if failure were to occur due to age and deterioration from corrosion and abrasion (Meegoda *et al.*, 2004).

SUMMARY OF LITERATURE REVIEW

The primary objective of literature review was to gather information on NJDOT drainage infrastructure and maintenance operations. Several keyword searches were conducted using the New Jersey Institute of Technology and Rutgers University public library databases, the Internet, and libraries of ASTM, AASTHO and of other DOTs. Information discovered during these searches cover technology citations, guidelines, methodologies. In addition, searches on published studies on pipe durability and hydraulic characteristics for various pipe material compositions, coatings, and environmental conditions provided guidance on our approach toward constructing a computerized data analysis methodology for the asset management module of DAIMS for NJDOT.

The need for identifying drainage infrastructures comes from the fact that transportation agencies develop extensive transportation networks that crisscross natural surface water features. Transportation networks therefore have a structural symbiosis with manmade drainage structures in order to mitigate flooding disasters and traffic hazards. A significant number of drainage structures are required to conduct the distribution and pathways of surface water. Hence, DOTs are responsible for a far greater inventory of culverts than bridges and other structures, and thus the investment in and importance of drainage infrastructures are enormous. Drainage infrastructures often go unnoticed as they are usually substructures, masked by ground cover, submerged, or placed in a remote location until a problem arises such as flooding, roadway settlement and even collapse.

It is in the best interest for departments of transportation to carry out comprehensive drainage infrastructure inspection on a regular basis to ensure that drainage systems are functioning properly and the report of such inspection are to be properly documented in order to determine whether a system requires repair, rehabilitation, or replacement.

Presently, there is no standard or consistent methodology to inventory, inspect, and evaluate culverts in the field. In order to ensure a successful drainage infrastructure inspection program, established standard guidelines must be put into place so that all data collected by inspectors are consistent. Visual inspection is the most common method of culvert inspection; however, some DOTs and road authorities also make use of video cameras. Typically, visual inspections lack consistency because they are carried out by multiple inspectors with differing biases. An all-inclusive database with facility to furnish data at the blink of an eye and generate condition summary reports would go a long way in saving NJDOT a lot of time, money, and resources in maintaining its drainage infrastructure. A storm-water information management system would serve in the form of a database for storm-water system with culverts/pipes and MTDs inventories and assist with recording locations, tracking condition and performance assessments, scheduling inspection and maintenance activities, and selecting and budgeting rehabilitation and replacement jobs.

It was also identified that information available from several past successful projects completed by NJIT would be very useful in putting together the basic structure of NJDOT's Drainage Identification, Analysis and Mapping System (DIAMS). For several years in the making, the foundation for the DIAMS Project came about from various frameworks. This included a comprehensive corrugated steel culvert pipe (CSCP) preventive maintenance study, a four-level condition state assessment based on the Caltrans system, an automated real-time culvert monitoring study, NJDOT Culvert Information Management System (CIMS) and literature of existing technology and test methods to provide both NJDOT and NJ's first inclusive drainage infrastructure identification, mapping, and capital investment technology system.

The Federal Highway Administration (FHWA, 1995) developed a comprehensive Culvert Inspection Manual that describes, in detail, inspection procedures, guidelines and inspection frequency, and requires that inspections be performed once in every 3 years (Arnoult, 1986). NCHRP Synthesis 303 on Assessment and Rehabilitation of Existing Culverts (NCHRP Synthesis 303, 2002) also documents the methods for inventorying, inspecting, and cleaning culverts and reported the following examples:

1. There is a need to establish a standard set of guidelines, under which all inspectors will inspect and consistently collect data.
2. New York State DOT and Connecticut DOT have comprehensive culvert inventory and inspection manuals that describe their culvert management program.
3. Some agencies cleanse their large diameter culverts between 2 – 3 year intervals.
4. There is need for a regular inspection schedule, similar to that provided in the National Bridge Inspection Standard (Gallivan, 2002). However, regular cycles are not followed by transportation agencies.

Culvert or pipe breakdowns and failures could lead to flooding if roads and embankments are not maintained properly; therefore, the safety of the public is one of the upmost concerns (Perrin and Dwiwedi, 2005). For the last several years, NJDOT has been actively engaged in identifying and cataloging culvert and pipe locations as well as inspection and condition information (NJDOT, 2010). NJDOT has recognized the benefits of enhanced data collection and a wide distribution of information and software applications would be highly valuable, not only interdepartmentally, but also to the New Jersey Department of Environmental Protection (NJDEP), FHWA, USEPA, American Association of State Highway and Transportation Officials (AASHTO), U.S. Army

Corps of Engineers, all state DOTs, counties, cities and both public and private engineering and design firms. In addition, to complying with NJDEP storm-water regulations, NJDOT is also required to report all discharges from culverts, which may potentially enter into New Jersey rivers and streams (NJDOT, 2010).

It is also imperative to update guidelines and procedures, to perform inspections and analyses of existing drainage infrastructures, including culverts, pipes, outfalls and Manufactured Treatment Devices (MTDs). These structures must be periodically inspected and evaluated to ensure satisfactory compliance with the requirements governed by structural, geotechnical and hydraulic standards and performance criteria (AASHTO, 2009). In addition, they must also meet changing and growing needs due to urbanization and other factors. Therefore, regularly scheduled and updated inspections, analyses, and condition rating guidelines are critical, as is a comprehensive management system to serve as a data warehouse of structure assets and to provide coordination of inspection, maintenance, rehabilitation, and replacement activities (Meegoda et al., 2005).

OBJECTIVES

The objectives of this research were to a) identify and catalog drainage infrastructure and b) provide a means of determining the optimum allocation of current maintenance budgets by identifying drainage infrastructure that are to be inspected, repaired, rehabilitated or replaced, and to comply with GASB-34 requirements. Also this system should be capable of making project level decisions to repair, rehabilitate, replace, or do nothing for a given drainage infrastructure.

Assessing the user’s cost or financial risk associated with failure is the most challenging issue in effective management for assets. One of the key aspects of this research was to forecast and develop inspection, cleaning and repair methods using the geographical information system and financial formulas to implement the best plan forward for the safety of our roads.

DRAINAGE INFORMATION ANALYSIS AND MAPPING SYSTEM (DIAMS)
The DIAMS is a two-layer information management system that consists of separate Structured Query Language (SQL) databases for pipes, inlet/outlet structures, outfalls, and manufactured storm-water treatment devices (MTDs). The 'front-end' of DIAMS is programmed on an Access 2003 application database with user-interfaces and queries for data review and manipulation. The 'back-end' consists of several database tables and related photo/movie files and reports. All database files are integrated into an effective data management system. Data supplied by contractors are saved as media files in different formats. DAIMS requires that the data be reorganized from these media before uploading them into the databases. In order to facilitate the data uploading processes, DIAMS currently uploads digital video files and stores them separately due to their size. Users can review, modify, save and delete database records in DIAMS to keep the system data up-to-date. Database records can be conveniently displayed with forms and reports with links to photos and videos.

The use of DIAMS starts with recording cleaning and inspection information of the pipes. Vendors would upload field inspection data including condition states into DIAMS via an online submission system. The estimations for the cost of pipes are integrated into DIAMS. Condition state values and cost estimates are used to compute the remaining worth of each asset in the system. The financial data analysis module allows users to make better-informed management decisions.

The DIAMS home screen is shown in Figure 2. It illustrates the four separate DIAMS modules: asset identification, data upload, financial analysis and system administration.

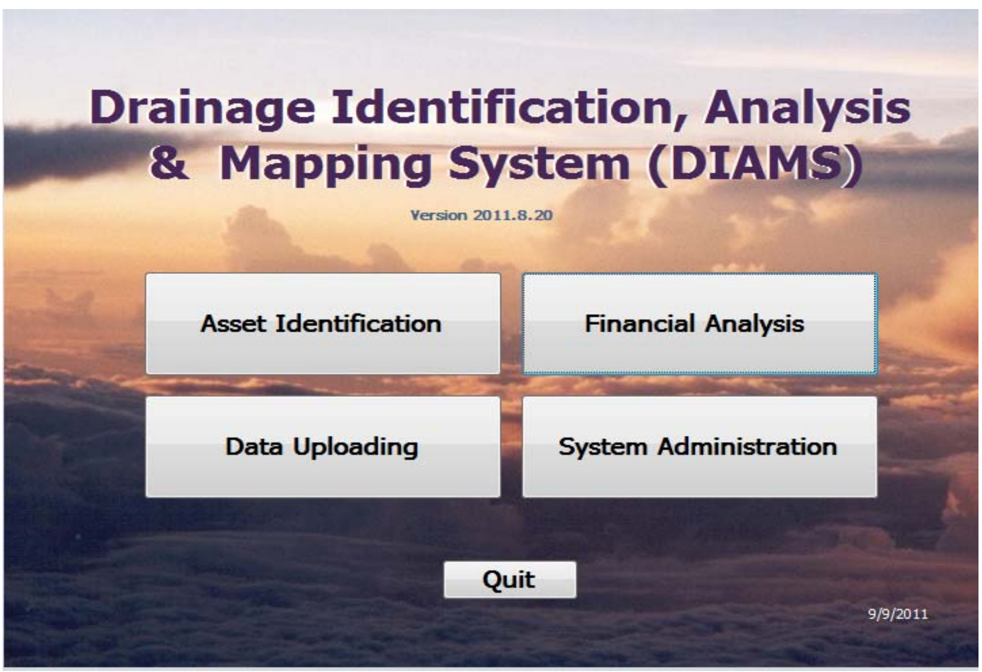

Figure 2. DIAMS Home Screen

The data upload module has various sub-nodes to ensure that the contractor-supplied field data uploaded to the database is unified and consistent. The asset identification module accesses the key attributes of the various physical components, and assigns functionality attributes to the inventory of drainage infrastructure. The system administration module supports low-level data reviews and editing, and the financial analysis compares maintenance and repair costs to design and extension of drainage network. The substructures of each module are shown schematically in Figure 3.

Figure 3 provides a schematic diagram of the operational details of the DIAM system with substructures of each module in Figure 2. This system is an outgrowth of the Culvert Information Management System (CIMS), which was developed under a previous NJDOT research project (Meegoda et al., 2009). The CIMS MSAccess database was updated to the new DIAM SQL database format and is included in the DIAM system, which consists of four functional layers:

1. Asset Layer – includes static and dynamic data obtained from Asset Inventory as well as Vendor Uploads
2. Application Layer – includes processed data as well as additionally provided external data, e.g., unit costs
3. Analysis Layer – includes ODBC and various optimization schemes with access to financial resource data
4. User Layer – includes outputs to reports, to the SLD, and eventually to the enterprise Data Warehouse

DIAMs Data Collection

One of the most critical factors in determining asset evaluation is the inspection and accumulation of field data through vendor inspections. For the past several years NJDOT has performed infrastructure inspections using analog videos and have saved the relevant information in VHS videotapes. The more recent inspections utilize digital photography, which accumulates a large amount of data that is difficult to process manually. Digital videos can be processed using a suitable image-processing scheme or simply by watching them to identify the critical sections and comparing them with historical information to identify Condition State.

The condition states, which are ranked zero to five, are as follows. The description for zero is an unknown condition and implications are to be addressed according to situation type. The description for one is excellent condition and no structural defects. The description for two is good condition and no likelihood of immediate collapse or potential for deterioration. The description for three is average and collapse is unlikely in the near future but further deterioration likely to happen. The description for four is poor and collapse is likely in the foreseeable future. Finally, the description for five is failed, and the structure has collapsed or collapse is imminently close. The above information and associated financial information will be used in making the required pipe management decisions. Pipes in the network should be inspected and Condition States should be known to make prudent management decisions.

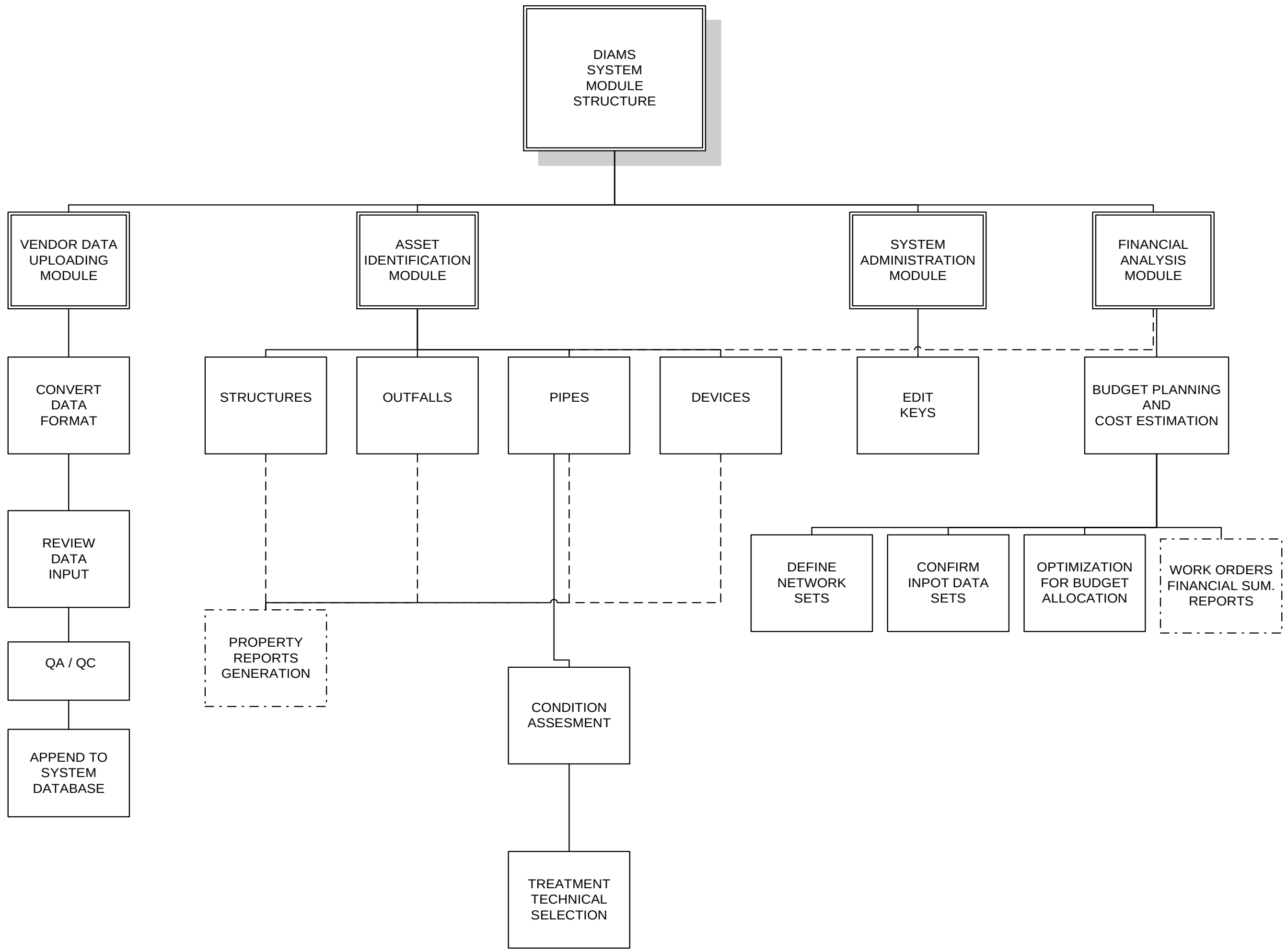

Figure 3. DIAMS Structure

The above information and associated financial information will be used in making the required pipe management decisions. Pipes in the network should be inspected and Condition States should be known to make prudent management decisions.

Uploading of DVD's will be done via online submission into DIAMS. Vendor data that has been collected through this process is arranged according to location, condition state, GPS coordinates as well as type of asset. The Data Uploading Module consists of a process of four sequential steps. First, the vendor data is converted from field inspections and formatted to DIAMS. Second, data is reviewed or updated into the system. Third, a quality analysis and control is performed. Finally, the system appends the inspection data to DIAMS database. This module provides the functionality for users to upload data databases (Access 2000 format) into DIAMS data database. The data are initially stored in an Access Database format and converted to a SQL Database after being uploaded. The details of the previously mentioned four-step data uploading process are as follows. First the vendor database is compacted into working template database. During the compacting process, the vendor name must be identified as being from the approved vendor list. Then the vendor data sets are appended into buffer data tables. The user could then choose options to manually check the vendor data integrity, e.g., make necessary modifications in key fields of displayed tables for structure names, types, route name, etc. By following system prompts, the user may also embed inspection photos into the buffer table records. After the vendor data are compacted into buffer tables, the vendor data sets are converted into required NJDOT data formats and checked for integrity. The system will briefly remind users if they have provided enough data inputs in the major data entry fields. The four converted buffer data tables may be reviewed before uploading them into the DIAMS data database. The final step will append the confirmed vendor data sets into the corresponding DIAMS data database tables so that users can review them with DIAMS Data Module interfaces.

Since the fully functional DIAM system will maintain an up-to-date inventory of eligible drainage infrastructure assets, condition assessments of those assets will need to be updated on a regular timetable using a replicable basis of measurement and measurement scale (Meegoda et al., 2006). In addition to the inspection digital videos, the continued collection of inspection and evaluation data of drainage infrastructure conditions will be complemented by the acquisition of new data, e.g., the effects of sediment accumulation within the pipe. Companion summary reports will note trends and any key factors that may have influenced trends in the information reported, and they may also include individual digital images of trouble spots as well as the digital video inspection file of the pipe.

Quality Assurance and Quality Control (QA/QC)

The Quality Assurance (QA) serves as a final check of the data, to locate any problems that may have been missed by Quality Control (QC) procedures carried out as the data is created. QA also serves as a regular test of whether or not the production and QC processes are producing data of the required quality.

The QA/QC procedure includes online data submissions. Vendors will be given a login to upload their data for initial screening. The QA/QC module is set up to verify data entries (existence (E), checking format (F), extract from NJDOT document (N), compare item with on existing dimensional (database) table (M), and check data limits (P)). The symbols (E, F, N, M and P) will be used to guide the QA/QC process and the final verification of data approval.

The system is designed to capture data inconsistencies from the data the vendors upload and then compare against the bid specification. For example, the vendors use their own convention to describe material type so that the potential for errors in the description attribute field requires rigorous QA/QC methods.

There should be consistent QA/QC for the condition state of structures and pipes. For example, in the condition state for the INSPECTION, the system will perform E, F, and M verifications, whereas the system only performs E and M checking for the ASSET table entries. The condition state for the PIPE ASSET is generated from manual inspection of video footage captured during inspection.

A quantitative check was used to validate the accuracy of the positional attribute of the DIAMS asset. A computerized check compared the asset coordinates to the road centerline coordinates. The latter dataset was obtained from the NJDOT's straight line diagram (SLD) database. In order to verify the acceptable limits of vendor-provided GPS coordinates, a simple radius search is performed. The circle radius will be determined based on project criterion and database functionality. The objective of this QA/QC is to check if the GPS coordinates are within a prescribed limit (say a circle of radius 0.1 mile) from the GIS coordinate. The concept is illustrated in Figure 4.

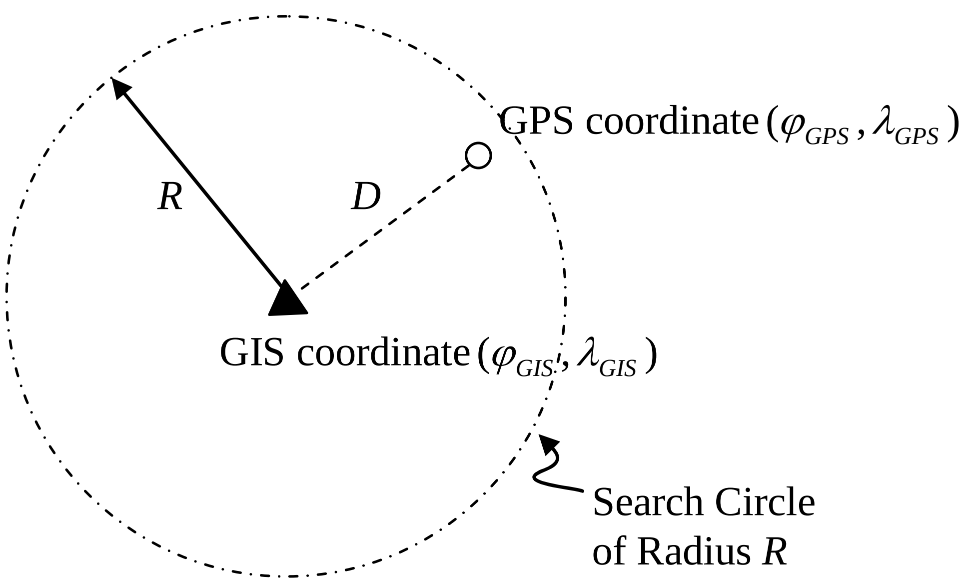

Figure 4. Quantitative Position Validation Procedure

In DIAMS the asset ID is developed from several geospatial features surrounding a particular asset. The ID is composed of a combination of the state route name, the nearest mile post, and the type of structure (manhole, catch basin, MTD etc.). The QA/QC process includes visual inspection of graphic displays of DIAMS assets overlain on an ArcGIS-supplied basemap (i.e., roads, census polygons, etc.). To check on the correctness of asset ID we used hierarchical proxies on location such as county, township and route number to verify the authenticity of the asset ID.

Asset Identification Module

Locating and assessing drainage infrastructure in a timely manner respective to their inspections require the skills to gather crucial information and the ability to analyze their probability of vulnerability over time. The information gathered through contracted drainage infrastructure inspections allows decision makers the ability to safely and proactively treat the condition assessment while allowing optimal financial cost benefits through the mathematical formulas presented over the long run. The quality analysis and quality reports that are used in the DIAMS assess the pipe condition states. Through research, a module will find the inspection, cleaning and repair unit costs according to their functionality of size and material type. Decision makers will have opportunities to choose and modify the types of information and input data in a manual form accordingly.

The DAIMS considers four types of drainage infrastructure (see Figure 5) namely structures (manhole, catch basins, head walls), outfalls (end of pipes, streams), pipes, and MTDs. Each of these type structures has its own data form that may be used to search and review the data for the particular type of structure.

<u>Structures Data Form:</u>

Inlet/outlet structures include all structures that are connected to pipes used to drain water from the surface of highways. The Inlet/Outlet Structure Data Form displays structure IDs and their attributes, as well as, their inspection results (see Figure 6). On top of the form, there are three combo boxes for the users to narrow down the searching scope for a particular structure record. Selections may be made for a location (Road); a rounded-up Milepost (one mile per interval); and inlet/outlet structure of interest to review the structure's records. On the upper portion of the form, structure asset information is displayed. The lower portion of the form contains related inspection information of the structure. Most data fields on this form may be edited to fill in missing data and save the changes. In order to keep data integrity, critical key fields should not be edited, such as 'Structure ID', 'Standard Route Index', 'Latitude' and 'Longitude'. They are supposed to be downloaded only from the source database. No asset record addition and deletion will be allowed at the present time. However, a new inspection record may be added for the current structure, or a photo may be embedded into structure records.

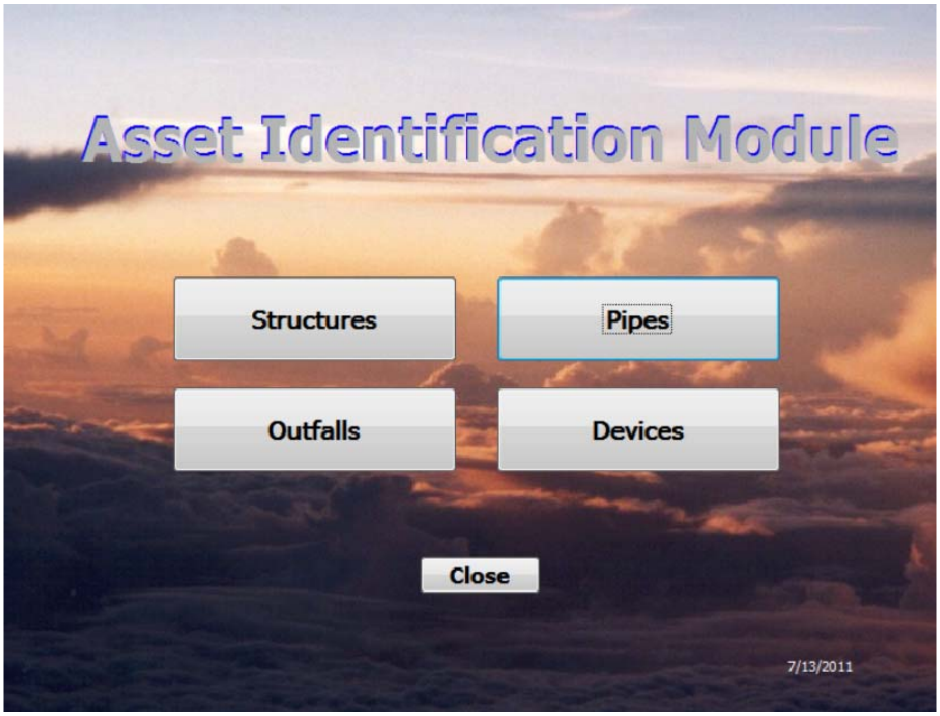

Figure 5. Asset Identification Module

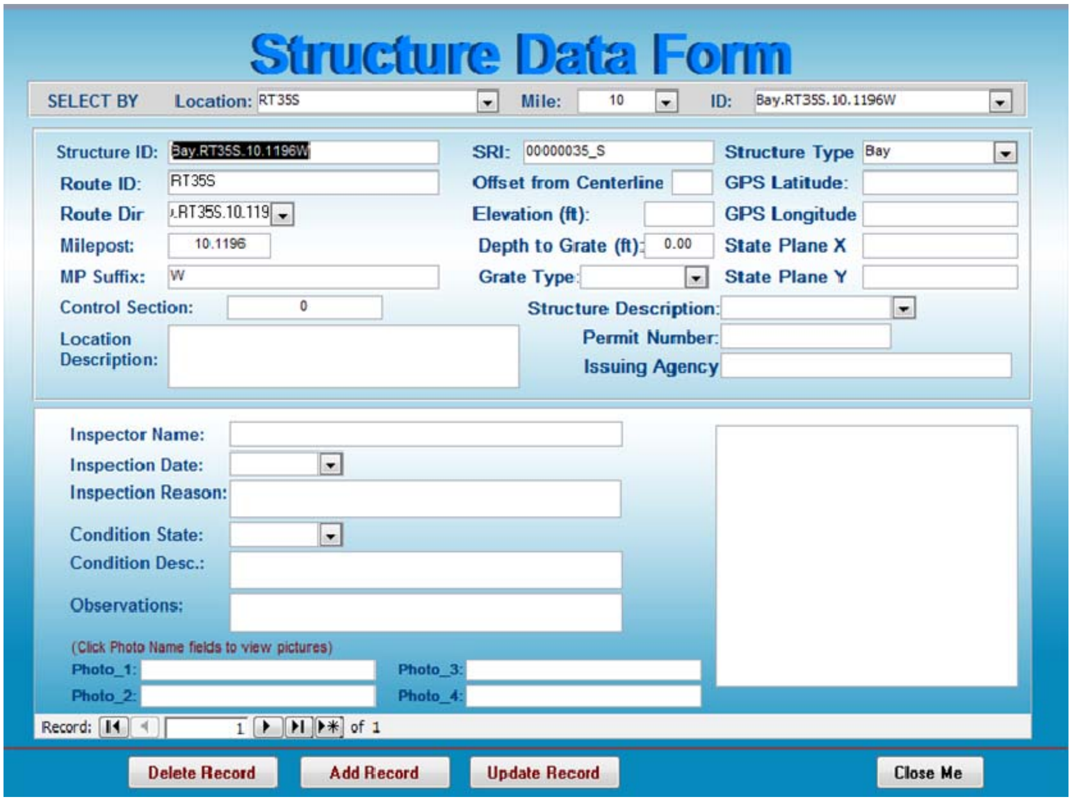

Figure 6. Structure Data Form

Outfall Data Form:

The outfall module has a form containing information for the outfall records. Users may narrow down their searching scope for an outfall record by first selecting a location (Road), then selecting a rounded Milepost (one mile per interval), and finally selecting the expected outfall that is close to the selected round-up milepost value to display the outfall record. The form also provides a list of all related inspection information for the selected outfall (see Figure 7). Most data fields on this form may also be edited to fill in missing data and save changes. In order to keep data integrity, critical key fields, such as 'Outfall ID', 'Route ID', 'Route Direction' and 'Milepost', GPS coordinates, etc. should not be edited. They are supposed to be downloaded from the source database only. Users can browse through all existing outfall records, by using the navigation arrows on the bottom of the main form. No asset record addition and deletion is allowed at the present time, but users can add a new inspection record for the current outfall, or add a photo to be embedded into the records.

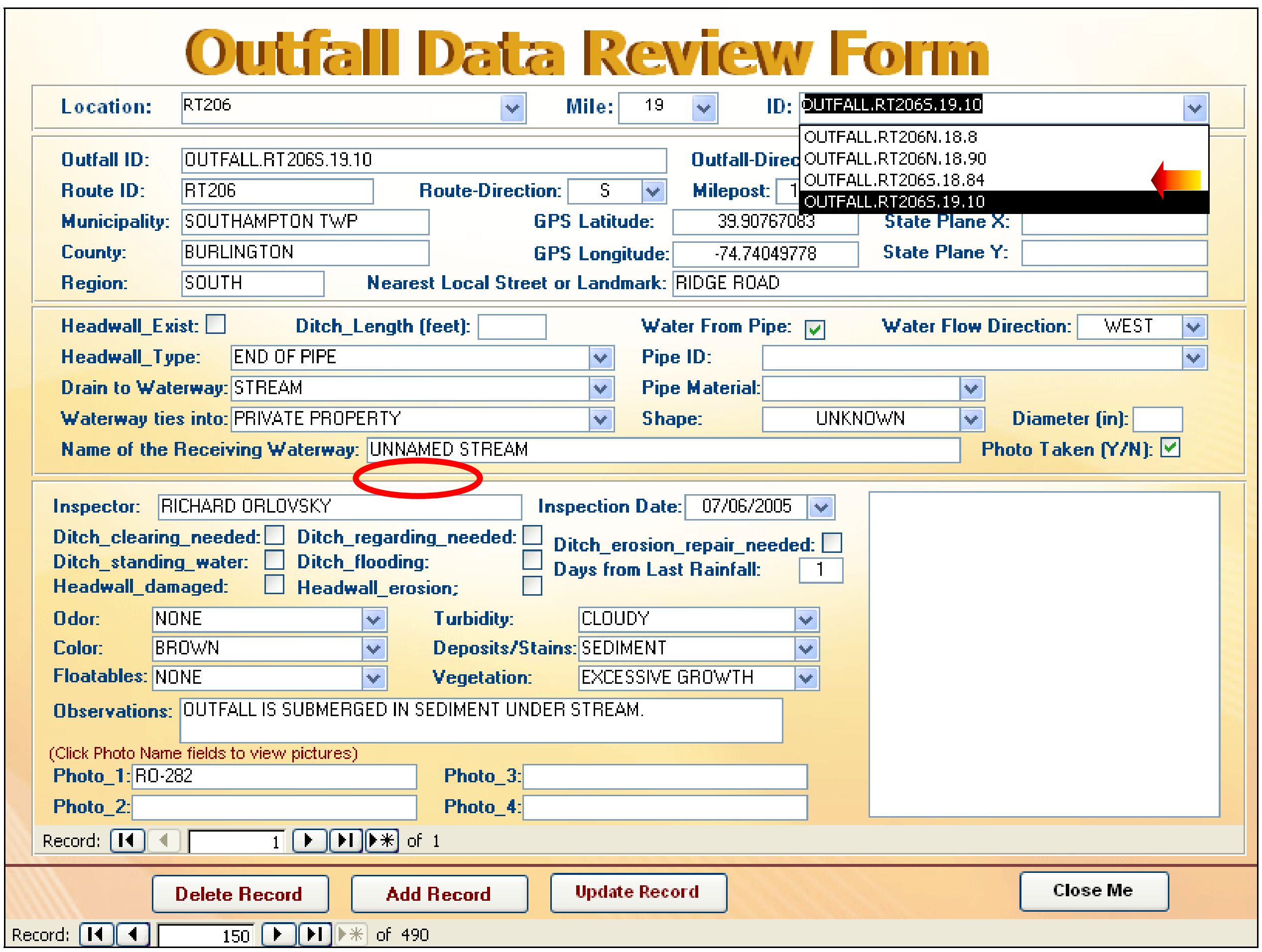

Figure 7. Outfall Data Review Form

Pipe Data Form:

The Pipe Data Form presents single record data information for a pipe segment. Similar to the Inlet/Outlet structure form, users may narrow the selection range of a particular pipe record by selecting a location (Road, City, State…), then the start-manhole, and finally selecting the end-manhole that will refresh the form to present a single pipe record (see Figure 8). Additional pipe records may also be retrieved, or users can directly select a pipe section record from the drop-down list. The pipe data form gives details of pipe asset data, as well as, a list of all related inspection information of the selected pipe including comments, photo file names, and movie file names, etc. Most data fields on this form may also be edited to fill in missing data and save the changes. In order to keep data integrity, critical key fields, such as ‘Report ID’ and ‘Video ID’ should not be edited. They should only be downloaded from the source database. No asset record addition or deletion is allowed at the present time. However, users can add a new inspection record for current pipe segment or embed a photo into the pipe records. A movie file may also be linked to the pipe data.

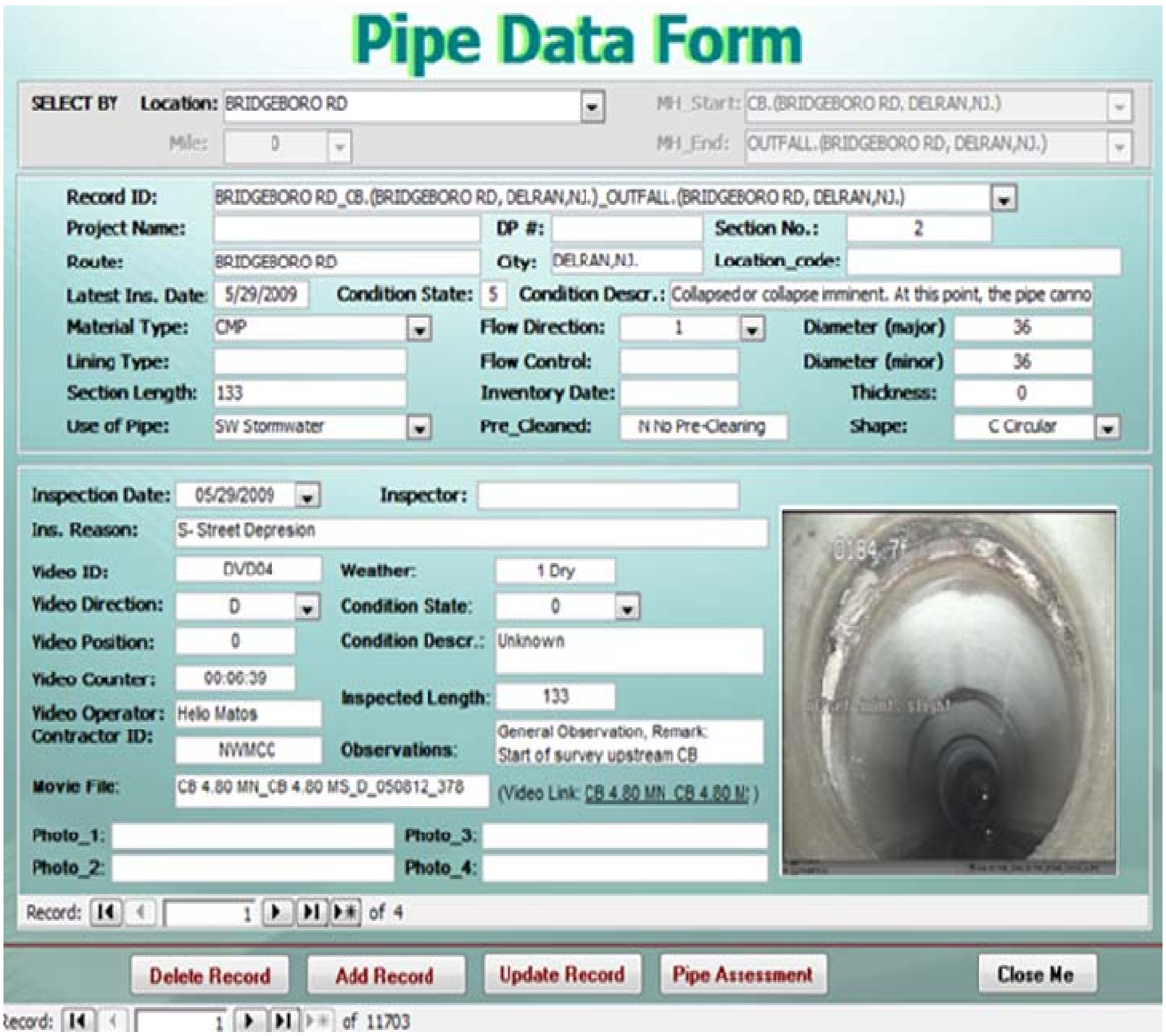

Figure 8. Pipe Data Form

<u>Device Data Form:</u>

Manufactured storm-water treatment technologies are designed for reducing storm-water runoff volume, reducing peak runoff rate, and reducing total phosphorus (TP). MTDs are also designed to remove highway trash and other pollutants such as nitrogen, oil/grease/hydrocarbons, heavy metals and bacteria. The MTD data entry form contains storm-water device asset data, inspection data and major maintenance records. All the information is contained in three tabular sub-forms under the following tabs: Device General Info., Inspection Information, and Maintenance Information. Users may search/specify the device ID, Type, and Model No. These three key fields will define the MTD category and attribute characters so as to link the device record to other related factual and dimensional data tables. For each device record, these three fields must be filled first in order to save the record into system databases. Due to the complexity and individual nature of the MTDs, specialized forms are provided for each manufacturer. Figure 9 shows the MTDs form for AquaShield.

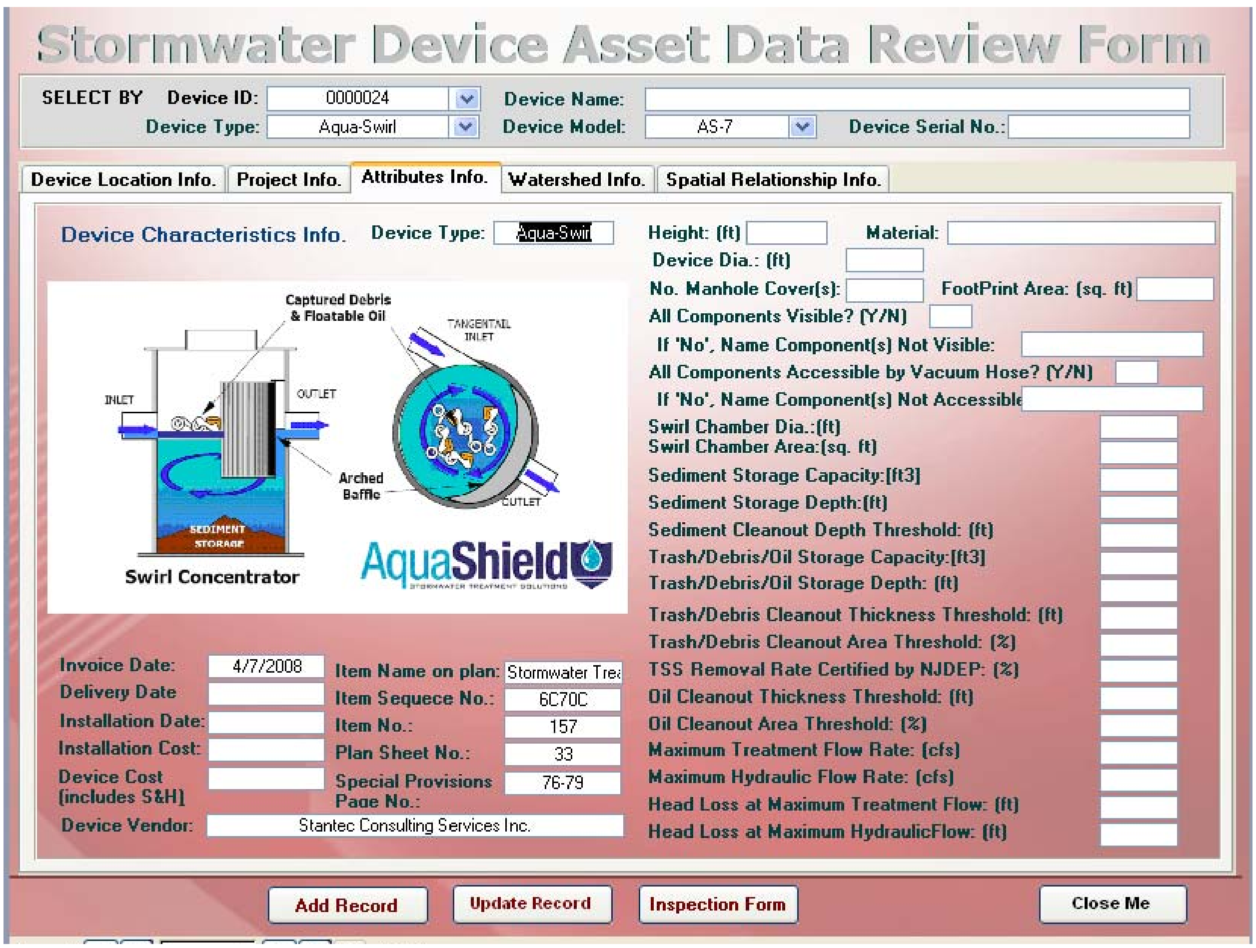

Figure 9. MTD Form for AquaShield

Financial Analysis Module

The DIAMS integrates Capital and Construction cost models capable of analyzing and reporting on the cost of drainage asset maintenance and operations (see Figure 10). The 72-item built-in Engineer's cost estimate (See **Table 1**) tool in DIAM will support planners/engineers in evaluating and making recommendations for best asset management practices. These scenarios include replacement, repair and rehabilitation or do nothing approaches based on a cost-benefit analysis.

At the project level, a drainage system infrastructure costs include expenditures for design, construction, maintenance, operation and administration. Costs for engineering, design and construction are called "first costs". Other costs, such as maintenance, operations and administration, occur continually, and are directly expressed as annual costs. All drainage asset costs are expressed as annual cost equivalents. Total capital costs (i.e. design, construction) may be expressed as annual equivalents using appropriate banking formulas assuming certain expected service life and interest rate. The annualized capital cost is then added to the annual costs of maintenance, operations, etc. to result in a total annual sum indicative of all drainage-related costs.

In starting a cost estimate, market value will provide the best available measure of value capital in terms of unit costs. The DIAMS incorporates unit costs based on 2010 RSMeans, a national U.S. yearly heavy construction cost estimating book and Bid Express, an online information service for bidding provided by BidX.com. Unit costs are incorporated into the New Jersey Department of Transportation (NJDOT) 72-itemized drainage restoration and repair contract bid as listed in Table 1 in order to estimate capital costs, asset worth, maintenance, repair and new construction costs.

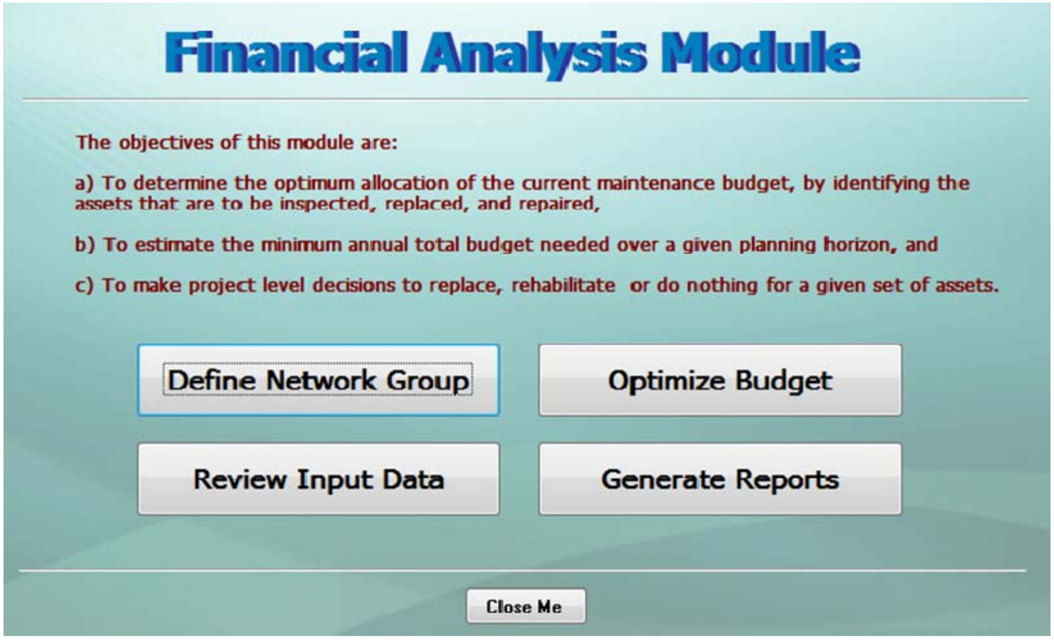

Figure 10. Optimization Module Switchboard Form

Table 1 – Unit Cost Table

NO	ITEM	UNIT	UNIT PRICE
151003M	PERFORMANCE BOND AND PAYMENT BOND	LUMP SUM	$10,000.00
152003P	OWNER'S AND CONTRACTOR'S PROTECTIVE LIABILITY INSURRANCE	LUMP SUM	$3,500.00
MMG007M	FIELD OFFICE EQUIPMENT	LUMP SUM	$7,500.00
MMG005M	CELLULAR PHONE SERVICE	LUMP SUM	$2,500.00
157003M	CONSTRUCTION LAYOUT	LUMP SUM	$30,000.00
MMD043M	MOBILIZATION OF DRAINAGE EQUIPMENT	UNIT	$2,500.00
MMG002M	FORCE ACCOUNT, LABOR	DOLL	$1.00
MMG003M	FORCE ACCOUNT, EQUIPMENT	DOLL	$1.00
MMG001M	FORCE ACCOUNT, MATERIALS	DOLL	$1.00
159003M	BREAKAWAY BARRICADE	UNIT	$15.00
159009M	TRAFFIC CONE	UNIT	$5.00
159006M	DRUM	UNIT	$15.00
159012M	CONSTRUCTION SIGN	S.F.	$5.00
MMR060M	FLASHING ARROW BAORD, 4'X8'	DAY	$50.00
MMG008M	TRAFFIC CONTROL TRUCK WITH CRASH CUASION & FLASHING ARROW BAORD,	DAY	$750.00
MMD006M	VARIABLE MESSAGE SIGN	DAY	$40.00
159141M	TRAFFIC DIRECTOR, FLAGGER	HOUR	$50.00
158006M	SILT FENCE	L.F	$5.00
158003M	CAUSION FENCE	L.F	$5.00
605212P	RESET FENCE	L.F	$15.00
158015M	HAYBALE	UNIT	$2.00
158045M	FLOADING TURBIDITY BARRIER, TYPE 2	L.F	$10.00
158072M	OIL ONLY EMERGENCY SPILL KIT, TYPE 1	UNIT	$1,000.00
MMD004M	FLOOD LIGHTS FOR NIGHTTIME OPERATIONS	DAY	$75.00
MMD039M	DISPOSAL OF TRASH AND BULKY WASTE	TON	$75.00
MMD041M	REUSE/RECYCLE OF SOIL/SEDIMENTS & MATERIALS	TON	$25.00
MMD025M	SLIP LINING 4" TO 24"	L.F.	$45.00
MMD025M	SLIP LINING 24" TO 48"	L.F.	$75.00
MMD025M	SLIP LINING 48" TO 72"	L.F.	$100.00
MMD029M	MINOR REPAIR OF STRUCTURES, LESS THAT 6' IN DEPTH	UNIT	$150.00
MMD030M	MINOR REPAIR OF STRUCTURES, GREATER THAT 6' IN DEPTH	UNIT	$300.00
602009M	INLET TYPE A LESS THAT 5' IN DEPTH	UNIT	$200.00
602009M	INLET TYPE A MORE THAT 5' IN DEPTH	UNIT	$300.00
602012M	INLET TYPE B LESS THAT 5' IN DEPTH	UNIT	$200.00
602012M	INLET TYPE B MORE THAT 5' IN DEPTH	UNIT	$300.00
602018M	INLET TYPE E LESS THAT 5' IN DEPTH	UNIT	$200.00
602018M	INLET TYPE E MORE THAT 5' IN DEPTH	UNIT	$300.00
602055M	MANHOLE	UNIT	$400.00
MMD009M	CLEANING AND VIDEO EQUIPMENT FOR PIPES AND STRUCTURES	DAY	$2,800.00
MMD024M	REPLACE PIPE 4" TO 24" DIAMETER R.C.P. (EDIT MATERIAL & UNIT PRICE)	L.F.	$75.00
MMD024M	REPLACE PIPE 4" TO 24" DIAMETER H.D.P.E. (EDIT MATERIAL & UNIT PRICE)	L.F.	$45.00
MMD024M	REPLACE PIPE 24" TO 48" DIAMETER R.C.P. (EDIT MATERIAL & UNIT PRICE)	L.F.	$90.00
MMD024M	REPLACE PIPE 24" TO 48" DIAMETER H.D.P.E. (EDIT MATERIAL & UNIT PRICE)	L.F.	$60.00
MMD024M	REPLACE PIPE 48" TO 72" DIAMETER R.C.P. (EDIT MATERIAL & UNIT PRICE)	L.F.	$120.00
MMD024M	REPLACE PIPE 48" TO 72" DIAMETER H.D.P.E. (EDIT MATERIAL & UNIT PRICE)	L.F.	$90.00
601760P	PIPE BEDDING	C.Y.	$35.00
601404P	SUB-BASE OUTLET DRAIN	L.F.	$30.00
158066M	ABSORBENT BOOM	L.F.	$10.00
158021M	TEMPORARY STONE CHECK DAM	C.Y.	$75.00
158024M	TEMPORARY SLOPE DRAIN	L.F.	$20.00
MMD007M	DISCHARGE PUMP	M.H.	$25.00
604003P	GABION WALL	C.Y.	$150.00
MMD021M	RIPRAP STONE PROTECTION, 6" THICK	S.Y.	$50.00
MMD021M	RIPRAP STONE PROTECTION, 6" - 12" THICK	S.Y.	$75.00
MMD019M	ROADWAY EXCAVATION, EARTH, LESS THAN 1.66 YARDS IN (VOLUME?)	C.Y.	$35.00
MMD020M	ROADWAY EXCAVATION, EARTH, GREATER THAN 1.66 YARDS IN	C.Y.	$60.00
MMD018M	SURFACE EXCAVATION	C.Y.	$70.00
202009P	EXCAVATION, UNCLASSIFIED	C.Y.	$25.00
202006M	EARTH EXCAVATION, TEST PIT	C.Y.	$85.00
302051P	DENSE-GARDED AGGREGATE BASE COURSE	C.Y.	$38.00
MMD017M	BITUMINOUS CONCRETE SURFACE & BASE COURSE	TON	$150.00
401030M	TACK COAT	L.F.	$3.50
606012P	CONCRETE SIDEWALK, 4" THICK	S.Y.	$40.00
607024P	9"X20" CONCRETE VERTICAL CURB	L.F.	$25.00
607087P	9"X8" HOT MIX ASPHALT CURB	L.F.	$20.00
609063M	RESET BEAM GUID RAIL WITH EXISTING POSTS	L.F.	$10.00
MMD042M	RETROFIT COVER PLATE FOR INLET CURB PIECE	UNIT	$150.00
801012M	SELECTIVE CLEARING	S.Y.	$15.00
MMD033M	TREE REMOVAL	UNIT	$150.00
806018P	FERTILIZING AND SEEDING, TYPE F	S.Y.	$7.00
804006M	TOPSOILING, 4" THICK	S.Y.	$5.00
807003M	TOPSOIL STABILIZATION, TYPE 1 MAT	S.Y.	$4.00

The total unit prices are gathered from the last column (Total Including O&P) for each item as found in the Existing Conditions, Concrete, Plumbing, Earthwork and Utilities sections of the 2010 RSMeans for items on the DIAMS Cost Estimate list. The RSMeans total unit prices include overhead and profit for material and equipment (about 10% of the total). In most cases, if the work is to be subcontracted, the general contractor will need to add an additional 10% to the total costs. Unit costs items, which were unavailable in cost estimation books were obtained from various NJDOT and Bid Express NJ contract bids and adjusted accordingly to the National Average for year 2010.

For DIAMS, the NJ unit prices are adjusted to the National Average (average of 30 major U.S. cities) using the CCI number of nearby NJ cities with similar economic characteristics to the location of projects. The RSMeans contains construction cost indexes for 316 U.S. cities. The City Cost index (CCI) number is a percentage ratio of a specific city's cost to the national average cost of the same item at a stated time period (RSMeans). The City of Paterson, with a factor of 110.2, was selected as the representative city for all projects performed in the North region of New Jersey. For the Central region, the City of Trenton was selected with a factor of 108.4. For the South region, Vineland was selected with a factor of 105.8. In the form of an equation as follows, the project cost is divided by the CCI number (expressed as a percentage, divide by 100) to obtain the National Average Cost (*NAC*) in equation 1 as shown below.

$$NAC = \frac{SCPC}{\frac{CIN}{100}} \text{ ------------ (1)}$$

Where, *SCPC* denotes the specific city project cost, and *CIN* denotes the city index number. For example, a pipe repair in 2000 on Rte 195 in NJ, in the township of Jackson cost $49,212 and the CCI equal 108.4 so that computed NAC is $49,212/(108.4/100) or $45,398.

The RSMeans Historical Cost Index (HCI) is used to convert national average construction costs at a particular time to the approximate construction costs for the project time using the time adjustment equation 2 shown below.

$$\frac{IY_A}{IY_B} \times \$Y_B = \$Y_A \text{ ----------- (2)}$$

Where IY_A and IY_B cost indices for years A and B respectively and $\$Y_A$ and $\$Y_B$ are the item costs for years A and B respectively. For example, to estimate the national average construction cost of the Route 195 Pipe repair in 2010, knowing that it cost $45,398 in 2000 with INDEX in 2010 (IY_A)= 183.5 and INDEX in 2000 (IY_B)= 120.9 would get, $45,398*(183.5/120.9) or $68,904. Hence, current cost estimates on construction costs and worth value are easily estimated based on a specific agencies' past projects.

The DIAMS financial analysis module is intended to produce a final product for work orders and financial summary reports. The simplified process of unit cost data incurred from pipe diameter size and type, estimating cost or manually input data, generating analysis with reports and a summary are key functions of the module. The process that is taken to develop the stages given as follows. Observations from vendors are collected via DVD video inspection data that includes information, comments, photo file names and movie files, are all input into the pipe data review form. The data review form consists of route identification, project name, diameter height, material type and location that can also be manually added to DIAMs. Data from pipes in the asset identification module are processed into a ranking system that is based on condition assessment. The condition assessments in turn will provide a technical treatment implementation suggestion upon the size and type of asset. Once information has been reported it is then taken through the financial analysis module and into budget planning and cost estimations that give definitive network sets according to various assets. Data from network sets are then confirmed for input data and a budget allocation for optimization is given. Finally, for demonstration purposes, the DIAMS developed a SQL statement builder form. It allows users to choose records they wish to display in a summary report. After a SQL statement is successfully generated, summary reports are built. This selection will open a report that displays the querying result based on current DIAMS database tables. The SQL builder querying results can be used to create a variety of customized summary reports. The following two forms explain the financial analysis of pipes in detail.

Pipe Assessment Forms:

The pipe assessment form enables users to choose pipe inspection or rehabilitation treatment techniques. It summarizes pipe material types, current condition, treatment cost as well as relevant date information for users allowing them to make operational decisions. From the current pipe condition and pipe age, the DIAMS will automatically take into account all available data about the selected pipe segment and reference to the pipe treatment policies defined by NJDOT (see Figure 11). DIAMS will automatically estimate and display the standardized pipe treatment costs for current pipe segment under review according to the pipe age, condition state, segment length and diameter as well as pipe material type information. (e.g., the Installation cost, the Inspection/Cleaning cost, the Rehabilitation cost and the Replacement cost). These standardized cost estimations come from a unit treatment cost table that could be modified in the editing system keywords module, based on user practice experiences.

Considering specific cost details, the user can request to estimate costs, which will open the cost modification form to make cost adjustments. A group of help buttons will guide users to consider certain relevant cost factors in estimating pipe treatment costs. The sub-module will guide users through a step-by-step process to estimate the do nothing cost used for the assessment process. By entering the cost item quantity, the sub-form will automatically calculate the total estimated rehabilitation cost for the pipe-repairing job. This estimated rehabilitation cost would be transferred back to the assessment form and recorded into database tables for later use. Combined with risk factors and consideration for user failure cost estimation, the system lists all suitable treatment techniques that the user can select. Users will also have the ability to compare their corresponding expenses. Based on the comparison, DIAMS will recommend or deny the user selection and remind the user to check existing data sets for accuracy.

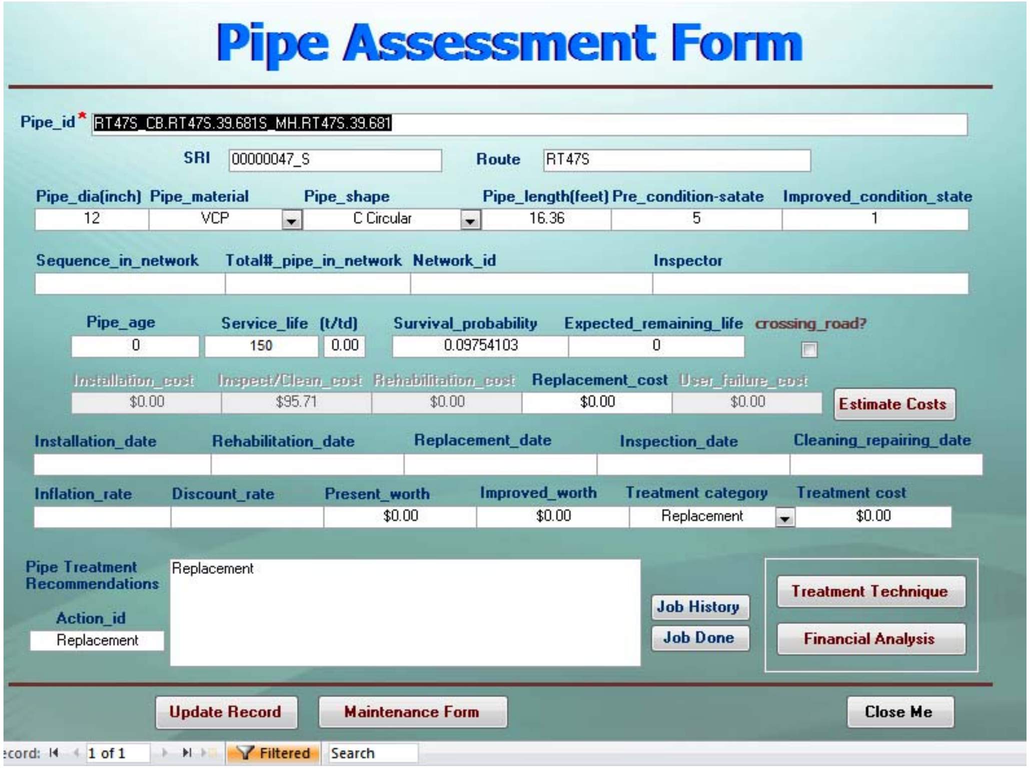

Figure 10. Pipe Assessment Form

Treatment Technique Selection:

Treatment technique selections are found in cases when both the pipe current condition state and pipe age are known. The treatment technique selection form displays the system recommended techniques and the current and improved condition states that are retrieved from treatment policy tables. Users can select the desired techniques and confirm treatment techniques, leading them to open the treatment cost justification form (see Figure 12). The form will automatically compare selected treatment technique costs, action costs, do nothing cost (i.e., the user failure cost) and notify the user if the selected action is justified, (indicated by text fields under the title justified). The user can either accept the system recommendation or input his/her choice. Once selected the recommend treatment technique will be saved in the decision comment text box and transferred back to the database. The decisions will be displayed on the updated pipe assessment form for the user to review.

Network Optimization:

The pipe assessment and optimization is the core component of DIAMS pipe financial analysis module. After the treatment techniques for the pipe segments have been determined, the user can define maintenance projects through the network optimization. Here, a project is defined as a group of pipe needing treatment within a certain amount of total budget (see Figure 13). With DIAMS, the user can search the optimal or near optimal solutions for the budget allocation among these pipe treatment jobs.

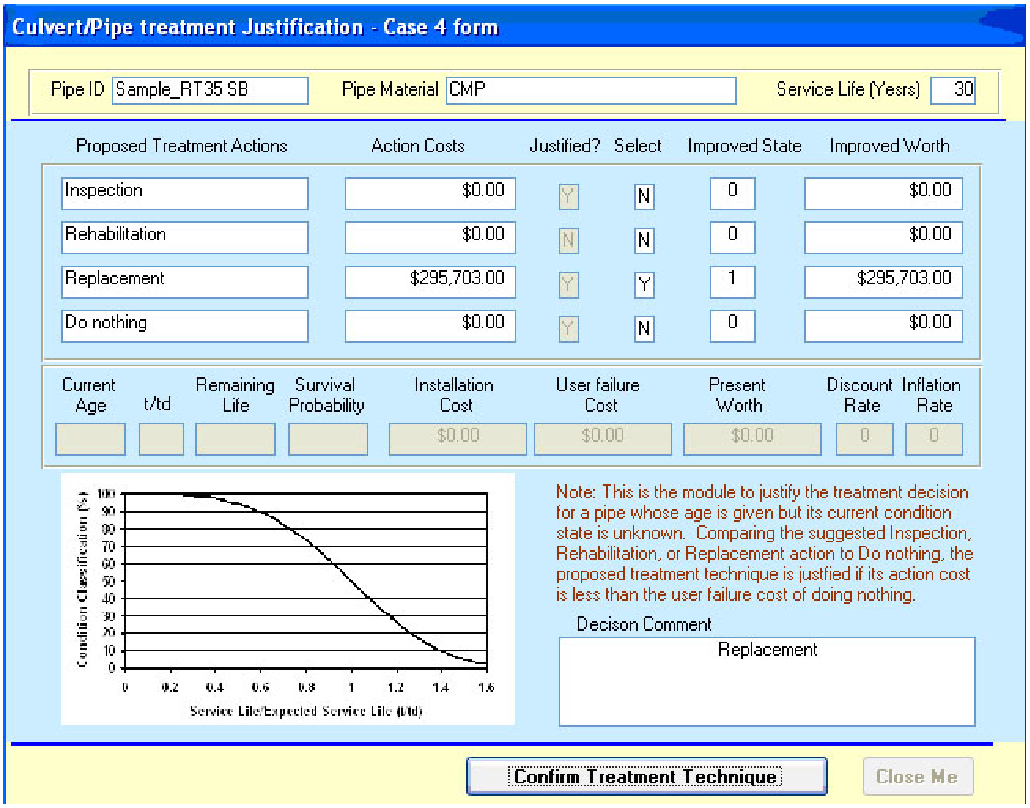

Figure 11. Structure/Pipe Treatment Cost Justification Form

The pipe financial analysis starts by grouping pipe segments into a particular project. Users have the option to select some of the segments to be included in the optimal solution no matter how much they cost. After a project has been defined the financial analysis module form will allow users to review the project input data where users are allowed to make changes to the input data. The pipe project optimization consists of four major components. The system will evaluate the input data set and summarizes its major attributions; such as how many pipe segments are in the project, the total capital cost are required, and how many are pre-fixed jobs as well as the minimum required capitals for these pre-fixed jobs (see Figure 14). The DIAMS has two optimization options, a heuristic procedure, such as ‘catch-the-big-fish’, or the 0-1 implicit enumeration algorithm that accounts for all possible combinations of the decision variables and compares their resulting objective function values to determine the real optimal solution. The reason for two algorithms is that the real optimal solution for the integer program problem has a 2^N computational complexity. When N>15, the enumeration will exceed 32768 combinations.

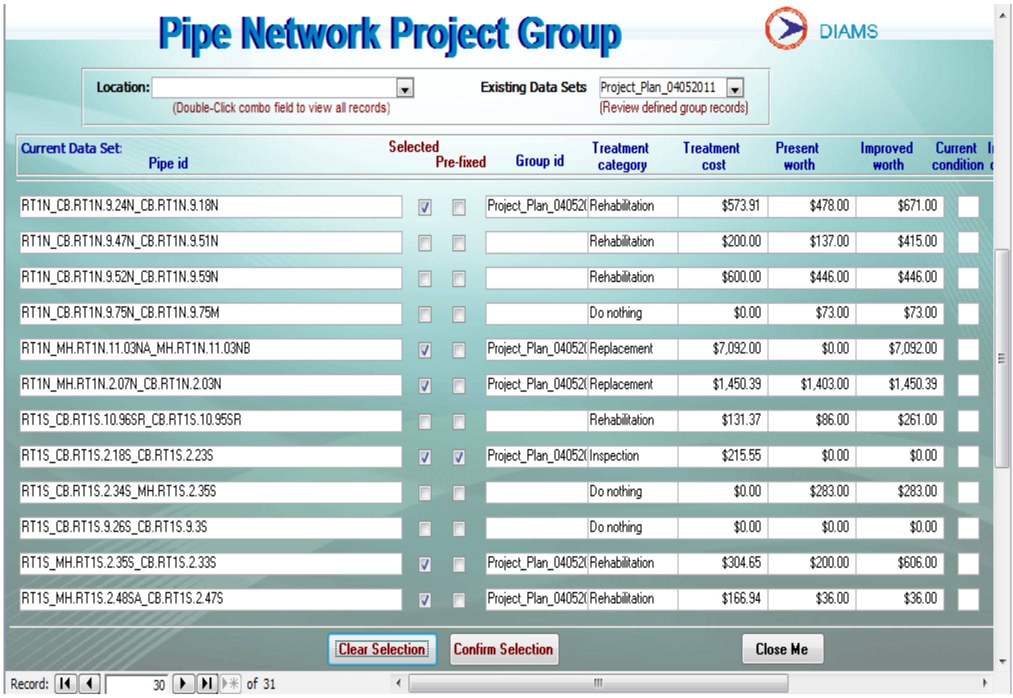

Figure 12. Pipe Network Selection Form

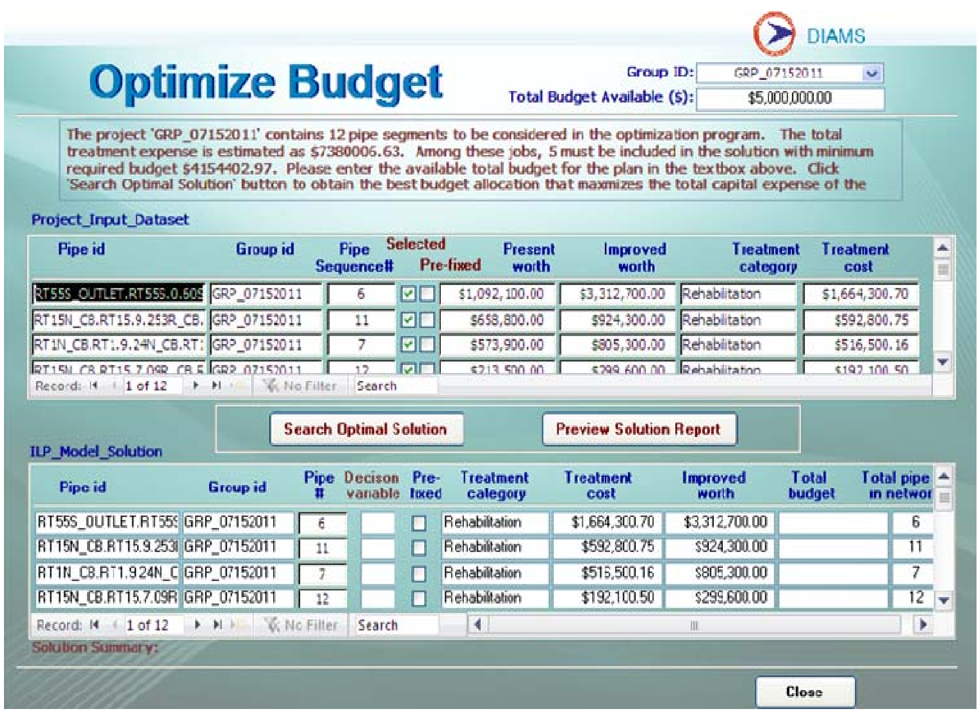

Figure 13. Optimize Budget Form

Although, the objective function and budget constraint are both simple linear additions, it may take a long time to evaluate all possible combinations when N is too large. The heuristic procedure is preferred when N>25. The heuristic approach covers the more costly segments first then the smaller ones until the available budget is exhausted.

DIAMS Report Generation:

Financial reports are an important part of DIAMS financial analysis module. These reports provide valuable information about the current status of the drainage system under NJDOT management. These timely generated reports are an effective tool for managers to set the priority of work orders and to schedule maintenance jobs in the most cost efficient way. Figure 14 shows one such report based on Network optimization.

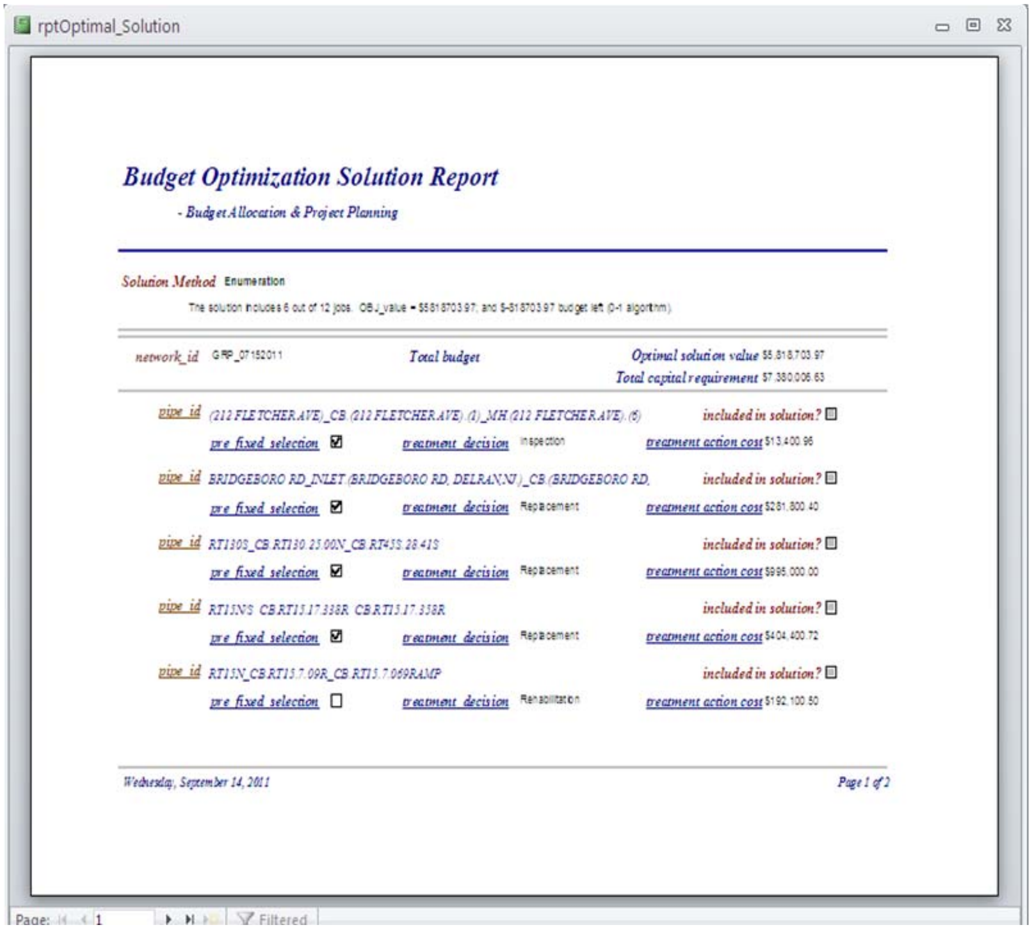

Figure 14. Sample Budget Solution Report

SUGGESTIONS FOR FUTURE RESEARCH

This project is a limited scope demonstration project of implementing the drainage information mapping system. There are several aspects that need further research and implementation. They are listed below.

1. The drainage information mapping system was developed in association with the NJDOT straight-line database. This should be upgraded to a database based on a geographic information system for visualization and planning.

2. The drainage information mapping system developed in this demonstration project contains only the assets inspected to date. To perform system wide optimization, one needs all information on all infrastructure assets in the state of New Jersey. Until that information is available, DIAMS will be unable to perform system wide optimization to comply with GASB 34 requirements. Hence, any future research should include the development of this component.

3. The DIAMS currently only considers in-kind replacement, which is not always possible. Therefore, the system should be upgraded to include replacement with different types of assets.

4. Since the majority of the assets are not inspected during the current year, a mechanism should be developed to predict the current condition state based on the past condition state. The historical records will help for financial analysis and planning purposes, but this capability involves substantial mathematical analysis, and hence it is proposed to be included in future developments.

5. Based on the current NJDOT administrative structure, capital investments and maintenance expenditure occur in two separate departments. However, DIAMS currently assumes that funds for both come from one source. Hence, the department might consider changing the administrative structure, or in the future, programs should split this into two separate optimizations.

6. Include a data streaming module for the NJDOT Video Inspection Van to upload directly into DIAMS.

7. Include the remaining structures (e.g. retention ponds, catch basins) for flood prevention purposes.

SUMMARY AND CONCLUSIONS

The following are the conclusions of this research:

1. Drainage Information Analysis and Mapping System (DIAMS) was developed. It is a two-layer system consisting of separate Structured Query Language (SQL) databases for pipes, inlet/outlet structures, outfalls, and manufactured storm-water treatment devices (MTDs). The ‘front-end’ of DIAMS is programmed on an Access 2003 application database with user-interfaces and queries for data review and manipulation. The ‘back-end’ consists of several database tables and related photo/movie files and reports. All database files are integrated into an effective data management system.

2. DIAMS is structured as four individual modules: asset identification, data upload, financial analysis and system administration. The data upload module has various sub-nodes to ensure that the contractor-supplied field data uploaded to the database is unified and consistent. The asset identification module accesses the key attributes of the various physical components, and assigns functionality attributes to the inventory of drainage infrastructure. The system administration module supports low-level data reviews and editing, and the financial analysis compares maintenance and repair costs to design and extension of drainage network.

3. Information gathered through contracted drainage infrastructure inspections allows decision makers the ability to safely and proactively treat the condition assessment while allowing optimal financial cost benefits through the mathematical formulas presented over the long run. Quality analysis and quality reports that are used in the DIAMS assess the pipe condition states. Modules will find the inspection, cleaning and repair unit costs according to their functionality of size and material type. Decision makers will have opportunities to choose and modify the types of information and input data in a manual form accordingly.

4. DAIMS considers four types of drainage infrastructure: structures (manhole, catch basins, head walls), outfalls (end of pipes, streams), pipes, and MTDs. Each of these type structures has its own data form that may be used to search and review the data for the particular type of structure.

5. DIAMS Financial Analysis Module integrates Capital and Construction cost models capable of analyzing and reporting on the cost of drainage asset maintenance and operations. It utilizes a 72-item built-in Engineer's cost estimate tool that will support planners/engineers in evaluating and making recommendations for best asset management practices. Unit prices are gathered for each item as found in the Existing Conditions, Concrete, Plumbing, Earthwork and Utilities sections of the 2010 RSMeans for items on the DIAMS Cost Estimate list. Scenarios include replacement, repair and rehabilitation or do nothing approaches based on a cost-benefit analysis.

6. DIAMS financial analysis module is also intended to produce a final product for work orders and financial summary reports. The simplified process of unit cost data incurred from pipe diameter size and type, estimating cost or manually input data, generating analysis with reports and a summary are key functions of the module. Data from pipes in the asset identification module are processed into a ranking system that is based on condition assessment, which in turn will provide a technical treatment implementation suggestion upon the size and type of asset.

7. Budget planning and cost estimations may be performed for definitive network sets according to various assets. Data from network sets are then confirmed for input data and a budget allocation for optimization is given. For demonstration purposes, the DIAMS developed an SQL statement builder form that allows users to choose records they wish to display in a summary report. After a SQL statement is successfully generated, summary reports are built. This selection will open a report that displays the querying result based on current DIAMS database tables. The SQL builder querying results can be used to create a variety of customized summary reports.

8. A limited scope pilot scale of the DIAMS was developed, tested and implemented for NJDOT. A detailed user manual and several on-site training sessions were also provided to ensure that NJDOT staff will be able to utilize DIAMS.

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