

4.0 SCIENTIFIC & TECHNOLOGY UNCERTAINTIES

4.1 Incorporation of Uncertainty in Plan Formulation

This discussion on S&T uncertainties is intended to illustrate that considerable information has been developed from prior studies but data gaps still exist and considerable scientific and engineering uncertainties remain. The LCA PDT recognizes those uncertainties and has formulated a plan with this recognition. Largely based on knowledge gained from research in the coastal zone and restoration projects constructed the past years under CWPPRA and earlier conservation construction efforts, the LCA Plan identifies a number of restoration features where uncertainties are limited (low risk). These features are given further consideration for implementation in the near-term with an imbedded AEAM and monitoring program. For those restoration features where science and technology uncertainty is deemed to be extensive (high risk), the feature presents the opportunity for implementation of an appropriately scaled demonstration project and/or research that serves to resolve the uncertainty. The S&T Office would serve an important role in both the AEAM of near-term restoration projects and in the engineering, design, and later AEAM of the demonstration projects. Investigations are expected to include both focused laboratory and field research efforts, as needed for each type of problem. The discussion that follows details the different broad types of uncertainties, with appropriate actions to resolve them during LCA Plan implementation. A more detailed discussion of this plan formulation process is in Section 3 of the Main Report.

4.2 Types of Uncertainty and Resolution Strategy Within the LCA Plan

There are numerous types of uncertainties to be addressed to support and improve LCA restoration efforts. Each uncertainty requires a different resolution strategy, based on the effects of the uncertainty on the program, degree of uncertainty, cost of addressing the uncertainty, and importance of reducing the uncertainty. Different strategies for resolving uncertainties may include, focused research projects, focused monitoring of existing projects or natural conditions, or demonstration projects. The latter strategy is discussed in further detail in section 4.3.

Uncertainties may be related to the science, modeling, socio-economic impacts, implementation, technical methodology, resource constraints, cost, or effectiveness of restoration measures. Uncertainties may also be related to development and refinement of forecasting tools. An uncertainty is considered critical if its resolution is vital to advancing the planning and implementation of the LCA Plan in the near-term. The role of the S&T Program is to identify and prioritize critical areas of uncertainty, to formulate the most appropriate means of resolving uncertainties, to ensure focused data collection aimed at resolving these areas of uncertainty, and to make recommendations to the LCA Program Manager regarding program and project refinements in light of the reduced uncertainty.

Critical areas of uncertainty identified by the PET, academics, or agency personnel will be proposed to the S&T Director. Proposed areas of uncertainty should be identified in relation to anticipated program activities. However, the S&T Office will not be constrained to targeting

only these needs, and will be open to facilitating the pursuit of new technology, experimentation, and innovative ideas when suitable for the advancement of the Program.

Areas of uncertainty will be prioritized based on the relative importance of resolution of the uncertainty to advancing the LCA program. The S&T Director will be responsible for determining the significance of the uncertainties relative to the advancement of the LCA Program in coordination with Program Management Team and PET.

Some of the known and most relevant uncertainties associated with the LCA Program are listed below, grouped by type of uncertainty. This summary also reflects the types of uncertainties and engineering challenges inherent in large-scale coastal restoration efforts and potential strategies to resolve them.

4.2.1 Type 1 - Uncertainties about Physical, Chemical, Geological, and Biological Baseline Conditions

The existing knowledge base regarding baseline conditions is sufficient (low uncertainty) to facilitate construction of many of the restoration features evaluated in the LCA Study. The expansion and evolution of new and existing tools and networks would provide additional baseline data throughout coastal Louisiana for more detailed program-level and project-level assessments. Some examples of basic baseline information needed to reduce scientific uncertainty include an understanding of the interaction of surficial and subsurface processes that impact the geomorphic features of coastal and deltaic plain. Understanding of sediment transport, accumulation and erosion processes and the net effects on coastal geomorphology are needed to restore features and support recovery of ecosystem processes and re-establishment of functioning habitats. Monitoring needs for these processes include accurate measures of bathymetry of coastal environments and rates of subsidence and sea level change. Accurate measurement of bathymetry and geomorphology of the coast have a profound influence on hydrodynamic model outputs and the sensitivity of many ecosystem models. Some specific examples of uncertainties and potential investigations designed to reduce the uncertainties are discussed below.

4.2.1.1 Determine relative sea level change and the processes that contribute to the overall rate of change within the coastal zone

Accurate elevations across the coastal zone are necessary for documenting and modeling subsidence and sea level change. Processes that contribute to subsidence include, but are not limited to, consolidation, faulting, fluid withdrawal, soil transport, and regional tectonic movement. Considerable work to address these processes has been done for specific locations of the coast.

In 1996, as part of the Morganza to the Gulf Feasibility Study, a contract report was prepared entitled “Datum Epochs, Subsidence and Relative Sea Level Change for Southeastern and South-Central Coastal Louisiana.” In 1995, the Barataria-Terrebonne National Estuarine Program (BTNEP) gathered elevation data in the Barataria Basin and Terrebonne Parish to evaluate subsidence rates. These data were compared to those in the feasibility report and a 1987

USACE funded report entitled “Terrebonne Marsh Subsidence Study”. Based on these data sources, for base conditions, apparent subsidence was assumed to be 0.54 ft (0.036 ft/year for 15 years) for all areas except “unhealthy” marsh areas, as identified in the BTNEP. “Unhealthy” marsh was assumed to subside a total of 0.74 ft (0.048 ft/year for 15 years). For future conditions, apparent subsidence was assumed to be 2.34 ft (0.036 ft/year for 65 years) for all areas except for unhealthy marsh areas where a value of 3.12 ft (0.048 ft/year for 65 years) was assumed. Subsidence is expected to magnify flooding problems for Terrebonne and Lafourche parishes in the future.

Although these studies provide valuable insight to subsidence rates in selected areas of the coastal area, other portions of the coast are not as well characterized. Currently, local, state, and Federal agencies, as well as private industry are working closely with the National Geodetic Survey (NGS) to establish High Accuracy Reference Network (HARN) monuments, NGS horizontal control monuments, and NGS vertical bench marks using GPS equipment to determine accurate horizontal and vertical positions relative to North American Vertical Datum of 1988 (NAVD 88) to meet the standards set forth by National Oceanic and Atmospheric Administration (NOAA). Once the GPS corrected elevation data are adjusted, the benchmarks would be published by NGS. This network of benchmarks would be used to help determine the processes contributing to site-specific rates of subsidence across the coast. This information is a critical component to future modeling efforts, which would influence future project design, cost, and success.

4.2.1.2 Collect detailed bathymetric data throughout the coast

Information from the studies discussed above for subsidence also provides valuable insight into the bathymetry of segments of the coastal. Several of the LCA Study modeling tools and most future numerical models require detailed bathymetry to compute water depth and other wetland characteristics, but these data are currently not available throughout the coast. There is a need to rapidly and accurately depict coast wide bathymetry and regularly update the data to reflect changes due to sea level change, erosion, subsidence, and sediment transport. The need is especially critical in the shallow, interior lakes and bays where data are difficult to collect.

4.2.1.3 Collect detailed topographic data throughout the coast

Several of the LCA Plan modeling tools relied on, and many future modeling efforts will require detailed topography to compute water depth, duration and frequency of inundation and other wetland characteristics. However, these data are currently not available throughout the coast. Application of technological advances such as Light Detection And Ranging (LIDAR), would allow for rapid and accurate depiction of coastal topography. To be most useful, these data would need to be regularly updated to reflect changes caused by sea level change, subsidence, erosion, and sediment transport.

4.2.1.4 Determine sources of material (sand, silt, and clay) to meet needs of restoration efforts

While much is known about the location, quantity, and quality of material available for use in restoration efforts, additional and unknown sources of material may be suitable and available to fit the needs of a particular project. Louisiana Department of Natural Resources (LDNR) is currently working with Mineral Management Service (MMS) to develop a central database of known sand resources. Existing data are being used to develop a plan for additional geological and geophysical data collection including sedimentological, high-resolution bathymetry, high-resolution seismic, magnetic, and side scan sonar data. These data will support modeling efforts to address geologic processes including sediment transport and linkages between nearshore and offshore environments. Knowledge of marine, estuarine and river currents, geomorphology and bathymetry and sediment availability in areas affected by land loss is needed to develop restoration approaches and to model the effects of project alternatives on geomorphologic processes and ecosystem responses.

The transport of sediment to be used onshore can be obtained from such sources as the Mississippi River. The quantity and quality of these resources (e.g., grain size distribution) are also available for restoration efforts. The USACE and USGS have collected hydrologic stage and discharge data for the Mississippi River and its distributaries for many years. There is a general understanding of the amount of flow volumes down both the Mississippi and Atchafalaya channels. However, a detailed analysis of the seasonal availability and qualities of the water/sediment stream are necessary to make strategic decisions about resource allocation within the system.

4.2.1.5 Establish a coast wide network of monitoring stations to support understanding of natural variability, reference conditions, performance measures, and provide a database upon which future modeling efforts can be built

Through CWPPRA, a Coast wide Reference Monitoring System (CRMS) for wetlands is being established to more closely monitor the effectiveness of restoration measures on reducing wetland loss along the Louisiana coast. Additionally, a CRMS coastal waters monitoring program and a Barrier Island Coastwide Monitoring (BICM) program are also being developed. Networking the CRMS and BICM to function as one comprehensive monitoring program would help address network needs to focus on all major ecosystem components. A diverse monitoring group of practitioners and scientists with appropriate technical expertise will need to be assembled to develop this integrated, comprehensive program. The SWAMP (described in **Section 3.3.2.2**) will integrate the monitoring of biological, chemical, physical and climatological variables in four modules: wetlands, barrier islands, inshore waters and rivers, and near coastal waters. A monitoring database and network that addresses physical, geological, biological, chemical and landscape components and/or processes of the ecosystem would be beneficial. Information derived from these studies would also address Type 3 uncertainties described below.

4.2.2 Type 2 - Uncertainties About Engineering Concepts and Operational Methods

There are several engineering techniques and operational approaches that could potentially enhance wetland restoration. However, associated technological uncertainties with the techniques and approaches warrant further investigation. For example, there exists a capability with currently available dredging technologies to transport sediments long distances through pipeline conveyance. Ponding hydraulics, sediment distribution at diversions, operational techniques, and different as means of sediment transport in open channels are other examples of uncertainties in engineering concepts. There is also a high degree of uncertainty about the availability of sufficient quantities of sediment resources and the sustainability of those resources.

In addition, uncertainties exist regarding the manner in which sediment materials can be properly discharged and dispersed to promote the establishment of new marsh vegetation while minimizing damage to existing marsh. Several of these uncertainties, and the potential investigations designed to reduce them are discussed below under Potential Demonstration Projects.

4.2.3 Type 3 - Uncertainties about our Scientific Understanding of Coastal Ecological Processes, Analytical Tools, and our Ability to Predict Ecosystem Response to Human and Natural Disturbances

Although numerous scientific studies have been conducted within the coastal environments, a considerable degree of uncertainty remains about ecological processes. Limitations in analytical tools to assess ecosystem responses also exist. Information obtained during baseline monitoring can be integrated into understanding ecological processes. For example, processes that influence land-water exposure also have a significant influence on the ability to accurately compute land loss rates. Ecosystem models developed and calibrated with data collected for baseline conditions and from monitoring efforts can be used to refine model outputs. Some examples of potential studies to address these uncertainties are provided below.

4.2.3.1 Develop a coast wide network of monitoring stations to support understanding of natural variability, establish reference conditions, assess performance measures, and provide a database upon which future modeling efforts can be built

This effort can address Type 1 and Type 3 uncertainties as discussed above.

4.2.3.2 Develop process-based models for prediction of land-building response to restoration measures

Models used to support LCA planning were developed and are discussed in detail in Appendix C. These models served as useful tools for evaluating restoration alternatives along with ecological benefits using a combination of modules that predict changes in physical processes and geomorphic features, and ecological succession on a basin-level scale. While

these tools were useful, refinement of the models and the incorporation of additional data, once it becomes available, would help reduce uncertainties. The incorporation of inorganic and organic components of the land-building process would be an important aspect in the refinement of the models. Current modules have been based on natural analogs from the Atchafalaya and Wax Lake delta that are of an inappropriate scale for application to many proposed restoration measures. Incorporating organic production into a land-building module would facilitate linkage with a habitat switching and productivity module.

4.2.4 Type 4 - Uncertainties Associated with Socio-Economic/Political Conditions and Responses

To date, the vast majority of modeling and assessment in support of the LCA Study has been derived from the natural sciences e.g., geology, ecology, and engineering. Though most of these studies are predicated on NER-based justifications and project costs, socioeconomic research is, by comparison, limited. Assessing the risks of coastal land loss in terms of dollars in market-based resources and infrastructure is limited by our understanding of the impact of ecological processes on economic conditions.. As part of LCA Plan Formulation an economic linkage study and an economic impact assessment study were commissioned. While these studies developed estimates of economic impacts within the coastal area for “Without Project Conditions,” more analysis would be required to detail NED costs and benefits at the project-specific level. To rectify this situation, socioeconomic modeling and assessment could be used to guide LCA Plan implementation.

Knowledge is not only limited on quantitative socioeconomic linkages to biophysical processes, but also on qualitative socioeconomic linkages. Social sciences should be integrated with physical and ecological sciences in the planning and management processes. By including the public as active participants in the planning and implementation process, issues involving alterations in life, work, recreation, values, and beliefs can be addressed. The following examples are part of the strategy to resolve the socio-political conditions and responses.

4.2.4.1 Spatial analysis tools such as socioeconomic GIS layers, and integrated models should be used to factor human uses of the environment into the analysis of ecological variables

To incorporate social issues throughout the life of the S&T Program, secondary census data trend analyses are needed to predict how social, cultural, and economic impacts may change over time. Trend analysis would also address the issue of how community interests fit with physical restoration efforts.

4.2.4.2 Economic impact and linkages

Input-output models can be used to determine how changes in particular sectors of the economy would affect the entire economy. Location Quotient Analysis describes how the local economy of a specific region compares to the national economy. Shift-Share Analysis clarifies how the shift in a share of a particular industry reflects on the local economy of a particular region. Research-based Benefit-Cost Analysis could prove complementary to internal analysis

and serve as a check against the premature limitation of restoration options resulting from institutional bias and inadequate calculations of social costs and benefits.

4.2.4.3 Economic risk assessment

Stochastic modeling could also be used to calculate the level of economic risk associated with landscape responses to various climatic probabilities (i.e. hurricanes, sea level change, and drought).

4.2.4.4 Sociology and anthropology have multiple research tools that could be used effectively in the LCA study

Surveys can be used to extract preferences for restoration alternatives at the local and parish level. Community modeling can provide useful information on the dynamics of industry, employment, and other demographic indicators that would be affected by coastal land loss and also by coastal restoration. Additional tools, possibly including the Social Impact Assessment, would be identified during execution of the S&T Program.

4.3 Demonstration Projects

4.3.1 Purpose and Need

The purpose of demonstration projects is to resolve critical areas of scientific or technical uncertainty and to advance the LCA plan by improving the planning, design and implementation of full-scale restoration projects. Although the scale at which demonstration projects would be implemented may be small relative to the scale at which the technology may ultimately be applied, information gained from demonstration projects could have direct applicability at the intended scale of action.

Demonstration projects should be based on sound scientific and technological theory and practice in order to test the uncertainty in a controlled manner. This strategy would serve to meet the goal of providing information that reduces scientific and engineering uncertainties. However, recognizing that there may be value in pursuing demonstrations of technology or technique combinations, that are new to restoration in Louisiana, there must be flexibility within the S&T Program to pursue demonstrations that are more experimental in nature when suitable for the advancement of the LCA Plan.

The information provided by the demonstration projects would be critical to advancement of the restoration program in the near-term. Both full-scale restoration opportunities and large-scale studies may depend upon results from demonstration projects to advance their planning and analysis of alternatives. In order to be responsive to program needs, demonstration projects must also have the ability to be implemented within 1-3 years and provide meaningful results in a relatively short timeframe as proven useful in CWPPRA.

4.3.2 Formulation of Demonstration Projects

The Director would determine the most appropriate way to address areas of uncertainty and work with the PET to reduce implementation risks. Resolution of uncertainty and timeliness of construction must be given great consideration in the formulation process. While resolution of an uncertainty may require that an entirely new project be built, projects currently in the engineering and design phase under CWPPRA, as well as existing restoration projects may be examined for their suitability in addressing the uncertainty. Additionally, opportunities to resolve multiple uncertainties within one well-designed demonstration project would be sought. Once approval by the Program Manager to pursue demonstration concepts is given, the S&T Office will work with the PET to develop necessary documentation to justify implementation.

4.3.3 Ensuring Focused Data Collection

The S&T Director would ensure that data collection and analyses within demonstration projects are aimed at hypothesis testing. Experimentation should be built into demonstration projects as well as existing projects as appropriate; however, collection and analysis of data must be carefully focused to ensure that the targeted uncertainty is adequately addressed. Data collection should be appropriate for resolution of the uncertainty both in the parameters measured as well as in time and spatial scales at which the data are collected. Additionally, proper experimental design must be ensured in order to allow for meaningful data analysis. Prompt reporting of results and recommendations regarding program and project refinements in light of the reduced uncertainty is needed to ensure that findings are useful in advancing the LCA Plan in the near-term.

4.3.4 Engineering and Design (E&D) of Demonstration Projects

The PET would be responsible for design and implementation of demonstration projects. The S&T Office would be directly involved in the E&D phase of demonstration project implementation to ensure that the project design is appropriate to address the uncertainty. The S&T Office would seek input from experts as needed to ensure that the project is designed and constructed in the most appropriate way.

4.3.5 Uncertainties that may be Addressed with Demonstration Projects

Listed below are some uncertainties that may be addressed through demonstration projects. These are primarily Type 2 uncertainty issues, but properly designed demonstration projects would clearly address several of the other types of uncertainties as well. These uncertainties were identified by the PDT and are expected to be the first to be addressed, but may be modified or replaced by uncertainties of higher priority as determined by the S&T Director. In order to support continued development of the LCA Plan through AEAM it is highly probable that additional demonstration projects will be needed. To avoid redundancy, they are only listed here although the other types of uncertainties are discussed within the short description of each demonstration project. This list will evolve throughout the life of the LCA Program.

4.3.5.1 Use of dredged material to restore coastal marshes using thin layer disposal techniques

There is the potential to distribute dredged material within interspersed marsh areas to increase elevation to a level suitable for vegetation to spread into currently open water areas and maintain function of existing emergent marsh. However, the depth and impacts on existing vegetation must be determined and techniques for proper dispersion to maximize plant growth and minimize suffocation of vegetation must be developed. Uncertainty about sources of sediments and appropriate particle size for enhancing productivity and maintenance of the marsh must be investigated. Therefore, it would be necessary to test different methods for thin placement including spray dredge and unconfined/semi-confined traditional hydraulic techniques. Traditional dredging would need a non-granular borrow source over vegetated platforms. Plant mortality should also be tested with different depths of fill. In addition, impacts related to the acquisition of borrow material and its effect on the local ecosystem must be addressed.

4.3.5.2 Methods and outcomes from sediment delivery via pipeline

This uncertainty could likely be addressed by the same demonstration project as the dredged material issue above. Concerns about the cost effectiveness of using conventional dredging techniques to transport large quantities of sediments long distances from sediment sources must be addressed. Conventional dredging equipment typically requires large pipelines for transport of sediments. However, there are uncertainties about how the material can be effectively transported efficiently over long distances and distributed within marsh habitats. Conventional equipment could result in large piles of sediments being deposited above tidal elevations, disrupting vegetative growth, and causing undesirable lateral water movements within the marsh. Therefore, techniques must be developed to effectively transport large quantities of sediments to the marsh and to carefully redistribute those materials within the marsh to appropriate elevations to promote marsh establishment. Additional tests should also be conducted to determine final grade vs. design grade, dewatering periods, and potential water quality effects of transported materials. Tests should also be conducted to apply a two-tiered approach whereby large pipeline systems are used to convey high volumes of material but smaller dredges could be used to then disperse the material into the marshes. Additionally, uncertainties regarding planting techniques on large scales need to be resolved. This demonstration could be used in combination with thin layer disposal described above to examine uncertainties associated with that technology. When offshore sediments are used, the effects of using highly saline material as they relate to creating a healthy marsh environment should also be considered. In addition, impacts related to the acquisition of borrow material and its effect on the local ecosystem must be addressed.

4.3.5.3 Sources for marsh creation, restoration of maritime forests, and restoration of freshwater cheniers

The effects of using saline mineral soils to support freshwater habitats needs to be examined. Uncertainties regarding the time required for soil to leach out salts and increase organic matter content in order to make the soils suitable for the establishment of freshwater

vegetation need to be resolved prior to using this technique on a large scale as does the reestablishment of woody habitat on cheniers, levees, and barrier islands.

4.3.5.4 Combining techniques of marsh platform creation and freshwater/sediment diversion

Individually, marsh creation and diversion techniques have been utilized successfully along the Louisiana coast. Combined, these two techniques may provide even greater results by creating land quickly while sustaining it in the face of relative sea level change. However, uncertainties need to be resolved prior to utilizing this combination of restoration techniques on a large scale. When creating a marsh platform alone, the area is filled to a height that would settle to marsh elevation after dewatering and compaction have occurred. When combined with a diversion, however, it may be more effective to build the platform to a lower elevation and allow the diversion to build the platform to a more natural elevation for marsh establishment. The best combination of initial platform height and diversion operation that would minimize cost and maximize benefits needs to be determined. The optimal height of a created platform also needs to be determined such that natural colonization by wetland vegetation can occur. Compaction rates related to construction of the platform should not exceed the rate of soil building so that the newly created areas are self-sustaining.

4.3.5.5 Operational strategies for water diversions

There would be opportunities to transport large quantities of river water into coastal marshes but uncertainties exist about the most effective operational strategies to maximize restoration benefits. Several recent studies on the Caernarvon water diversion have indicated the potential to enhance marsh establishment below the diversion by altering the operational strategy and moving water out of canals and into adjacent marshes. Additional studies are needed to test different operational strategies including pulsing methods and timing of delivery of freshwater, sediments, and nutrients from diversions to optimize long-term sustainability of marsh landscapes. There are also concerns about potential water quality degradation due to high nitrate levels in the river water. Therefore, it would be necessary to determine seasonal dynamics of nitrate levels in water sources and determine the assimilative capacity of different coastal vegetative species and different coastal wetland types.

4.3.5.6 Sediment sources for reestablishment of barrier islands and land bridges

Much has been learned about the most effective and sustainable island geometry design from focused research and restoration projects already completed. However, many issues remain regarding the potential sources of the large quantities of sediment that are required to reestablish coastal barrier islands. Two sources already identified are Ship Shoal and the Lower Mississippi River. Issues related to Ship Shoal, a large sand deposit south of Isle Dernieres, are the quantity of available material and the cost effectiveness of using this source relative to other sources. The sources of sands must be clearly identified and different transport mechanisms tested to determine a cost-effective approach to establishment. Studies are also needed to ascertain the type of sediment (percentage of sand/silt/clay) that may be used for barrier island/back barrier marsh creation while facilitating vegetation growth and island stability. Presently only a few

blocks in Ship Shoal are known to be devoid of oil and gas infrastructures and thus the sand from these blocks could be dredged for restoration projects. Geotechnical investigation may be undertaken to determine the availability of sand for restoration from other blocks of Ship Shoal as well as other sand bodies in the Outer Continental Shelf (OCS), for example, Tiger Shoal, Trinity Shoal, and Sabine Bank.

4.3.5.7 Remediation of canals for marsh restoration

Canals have been cut throughout coastal marshes and their associated dredged material banks have resulted in fragmentation and accelerated loss of many marshes. There has been considerable uncertainty and debate about the most effective approach to remediation of existing canals. There are also uncertainties about the viability of associated marsh restoration efforts and the timing of restoration. Several different approaches to marsh restoration in existing pipeline canals should be examined and monitored including: (1) backfill with small hydraulic dredge; (2) cross dikes to construct cells and improvements on effluent discharge location; (3) mechanical backfill; (4) gaps in the spoil bank to restore natural hydrology where appropriate; and (5) test plugs as stand-alone features to reduce erosion within the canal. If backfill is used, impacts related to the acquisition of borrow material and its effect on the local ecosystem should also be addressed. Elevated spoil banks may provide important wildlife refugia during storm events and valuable habitat for neotropical migratory birds, and the relative value of this habitat must be evaluated against the system needs for restored hydrology.

4.3.5.8 Erosion protection structures

Erosion along open bays and channels has led to wetland losses across the coast. Different approaches to impede future erosion must be examined and effectiveness determined. Methods of construction and prediction of constructed structure sustainability should also be determined. Settlement of various erosion protection/foreshore protection features must also be determined. Efforts would be necessary to construct and monitor a variety of erosion protection/foreshore protection features in a variety of foundation conditions. Improved designs and more accurate project cost projections would also benefit all future related work.