Synthesis of Hydrologic and Hydraulic Impacts: Technical Report

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DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
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16. Abstract

A substantial portion of the cost of highway projects (approximately 40%, according to one in-house TxDOT estimate) is for drainage infrastructure, which is intended to minimize any adverse hydrologic and hydraulic (H&H) impacts of the project. Yet, adverse H&H impacts are not well-defined, despite the cost invested in drainage structures for mitigation of such impacts. This report provides guidance towards defining adverse H&H impacts and recommendations for their mitigation. A minimalistic approach towards defining and mitigating adverse H&H impacts would fulfill minimal legal requirements while taking into account the sovereign immunity enjoyed by state agencies such as TxDOT. A literature review and surveys of state Departments of Transportation as well as TxDOT districts suggest that this minimalistic approach be discouraged in favor of an emerging "No Adverse Impact" approach. For better defining and mitigating adverse impacts TxDOT is to refine coordination with local floodplain administrators, optimize site visits by District Hydraulic Engineers and other designers because of centralization, continue to improve H&H modeling and documentation, disseminate best practices regarding drainage system design, and have ongoing training relating to particular H&H issues. Implementation of the recommendations may require a change in the status of the District Hydraulic Engineers.

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DISCLAIMER

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1. INTRODUCTION

As development occurs, the movement of rainwater through a watershed is altered, potentially causing increased erosion, flooding, or other adverse impacts. The Texas Department of Transportation seeks to further develop its capacity to identify and mitigate such adverse impacts.

The impact of development on the movement of water through a watershed may be understood in part by considering the destination routes of precipitation, as shown in Figure 1.1. Development brings with it an increase of pavement and other relatively impervious cover, thereby causing a greater portion of precipitation to become overland flow rather than infiltration. The increased surface runoff volume is not only greater, but also flows at a disproportionately higher rate, as shown in Figure 1.2, so flooding and erosion may increase.

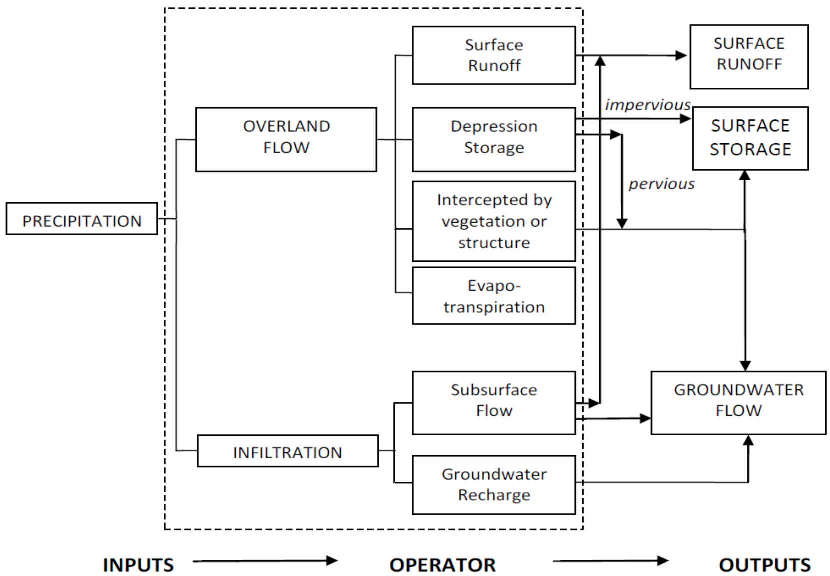


Figure 1.1. Schematic of Hydrologic System with Surface and Subsurface Flows (Cantone, 2010).

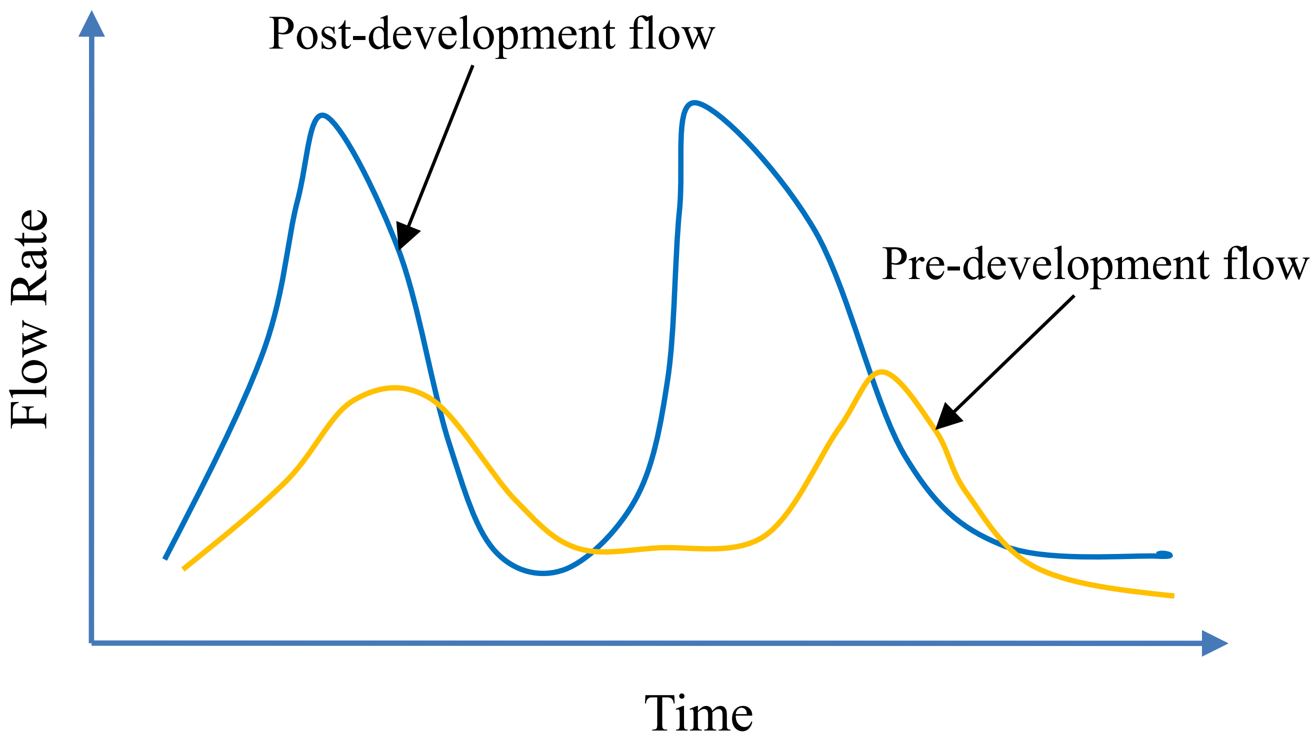


Figure 1.2. Modification of Hydrograph due to Development.

The reduction in infiltration due to the impervious cover has other impacts that may be easily overlooked. The groundwater supply may be reduced. Also, groundwater flow to wetlands and streams may be reduced, thereby damaging ecosystems.

When compared to development in general, TxDOT roadways contribute a relatively small increase in impervious cover, and may not directly have a significant impact on the dynamics displayed in Figures 1.1 and 1.2. However, the roadways are typically elevated above their surrounding ground and have the potential to divert or impound overland flow. They typically must be designed with roadside channels or other conveyors to carry flow significant distances along their length. Where roadways cross streams, culverts or bridges may be used to accommodate passage of stream flow. Open roadside channels, storm drains, culverts, and bridge crossings must all be carefully designed so as not to contribute to backwater effects (i.e., an increase in upstream water surface elevations due to downstream constrictions) and an increase in upstream flooding. They also must be designed not to contribute to higher flow velocities and greater erosion and flooding downstream. The roadway drainage system must therefore achieve a balance such that neither the upstream nor downstream effects are significantly worsened. Achieving that balance for both present and future conditions at a reasonable cost may not be possible if the local governing entity allows that land to develop with little surface runoff regulation. Such unregulated development may lead to stormwater flows that exceed the design capacity of TxDOT drainage infrastructure, thereby damaging the roadway and causing catastrophic losses upstream and downstream of the roadway. TxDOT infrastructure and the surrounding land are to develop so as to avoid such impacts to water flow.

The impact development and TxDOT projects may have on the movement of water fall into two general categories: hydrologic impacts and hydraulic impacts. Hydrologic impacts concern flow volumes and flowrates, but are not concerned with velocities and water surface elevations. Hydraulic impacts concern velocities, and the water surface elevations that correspond to those velocities. The flowrate, which is a volume of water moving per unit time and is shown as a function of time in hydrographs, is suggestive of velocity but actually falls under the hydrologic rather than hydraulic category; the flowrate must be divided by the cross-sectional area through which it passes in order to calculate velocity as a hydraulic quantity. Table 1.1 lists various aspects of TxDOT projects and examples of hydrologic and hydraulic impacts that may result. The table is for illustrative purposes only and is not intended to be exhaustive.

Table 1.1. Examples of Potential Hydrologic and Hydraulic Impacts That May Result from Features of TxDOT Project.

TxDOT Project Feature	Potential Hydrologic Impacts	Potential Hydraulic Impacts
Adding exterior lanes to roadway	Decrease in infiltration to underlying aquifer; increase in peak flowrate exiting ROW via roadside channel	Increase in velocity of flow exiting ROW via roadside channel
Increasing road profile elevation	Increased infiltration upstream of roadway; Reduced hydrograph peak downstream of roadway during overtopping event	Increased backwater elevation and flooding upstream of roadway
Increasing culvert diameter at stream crossing	Increased hydrograph peak, especially downstream of roadway	Increased velocity and decreased water surface elevations upstream of roadway
Construction of an embankment for a new roadway	Reduced infiltration and groundwater recharge due to interception of overland flow	Development of high velocities along embankment, leading to need for roadside channel to prevent erosion

Exactly what constitutes a hydrologic or hydraulic impact which is to be avoided varies among communities and states. In order to facilitate discussion in this report, the term “adverse” will be used to refer to impacts which are discouraged or prohibited through federal laws, state laws, local ordinances, or the policies of an agency such as TxDOT. The authors hope that TxDOT and other state DOTs find this report helpful in defining and mitigating adverse impacts.

The need to define and mitigate adverse impacts must be emphasized. Throughout the United States, there may be a natural tendency to underestimate the importance of drainage issues in the design of roadway projects as they are incidental to the purpose of such projects – to transport vehicles. Yet, experienced TxDOT personnel are aware that the costs of these drainage structures are substantial. One veteran TxDOT hydraulic engineer recently analyzed costs for a representative diversity of TxDOT roadway projects and found that drainage structures accounted for an average of approximately 40 percent of costs. This study is an effort to assess how the various state DOTs and TxDOT mitigate any adverse hydrologic and hydraulic impacts their projects may have, so that most appropriate practices might emerge and be documented. This project is also intended to assess how districts may need to be assisted in achieving those best practices. The assessment is to be achieved primarily through surveys and interviews administered to the districts and state DOTs. In summary, this study is a response to TxDOT's desire to best utilize public funding for the good of the public in relation to adverse hydrologic and hydraulic impacts.

2. LITERATURE REVIEW

An effective survey can only be developed after relevant issues have been identified. An important means for identifying these relevant issues is by a literature review that explores key aspects of drainage design for TxDOT roadway projects (Figure 2.1). Firstly, the transportation function (highway, airport, etc.) and the hydraulic features (roadway crossing over a stream; an embankment intercepting overland flow; etc.) cause various hydrologic and hydraulic impacts. At least some of these impacts will be undesirable, typically, and generate the need for hydraulic engineering and form the basis for this literature review. Each of the remaining blocks in Figure 2.1 is therefore represented in the literature review, with the section indicated in parenthesis. Data collection (Section 2.3) is needed for estimation of various hydrologic and hydraulic quantities (Section 2.2), so that the impacts of the proposed project may be predicted. Design alternatives (Section 2.4) are to be considered for mitigating those impacts, but only those alternatives that meet the design criteria are feasible (2.4). These design criteria may be based on law, TxDOT policy, a quantitative risk assessment regarding private property neighboring the project, or other concerns. Finally, data collection (2.3) concerning maintenance issues and other life cycle costs is needed to optimize the design (2.4).

The one-way direction of the arrows in Figure 2.1 is a simplification of what happens in practice. For example, estimates of hydrologic and hydraulic quantities may be unrealistic based on the initial data collection, creating the need for collecting additional data, suggesting a reversal of the arrow. Similarly, the estimated hydrologic and hydraulic impacts resulting from a particular design alternative may be useful in considering other design alternatives, again suggesting a reversal of the arrow direction. The directions shown are intended to represent the general direction of activity.

Not explicitly shown but necessary for the success of activities shown in Figure 2.1 is the interaction required between the hydraulics engineer and other engineers and agencies and documentation requirements. These aspects are well covered in the soon-to-be-published TxDOT Hydraulic Design Manual (2011), hereafter referred to as TxDOT HDM (2011), and the currently used 2009 edition of the TxDOT Hydraulic Design Manual, hereafter referred to as TxDOT HDM (2009). This literature review does not repeat the substantial work already presented in these manuals, but references them as necessary to display the complete set of issues relevant to the survey development.

This literature review is unusually broad because of the multiple objectives of this project. Through the surveys and interviews, particular issues may arise that invite further investigation of the literature. The results of such investigations will be presented as part of the discussions of the survey and interviews.

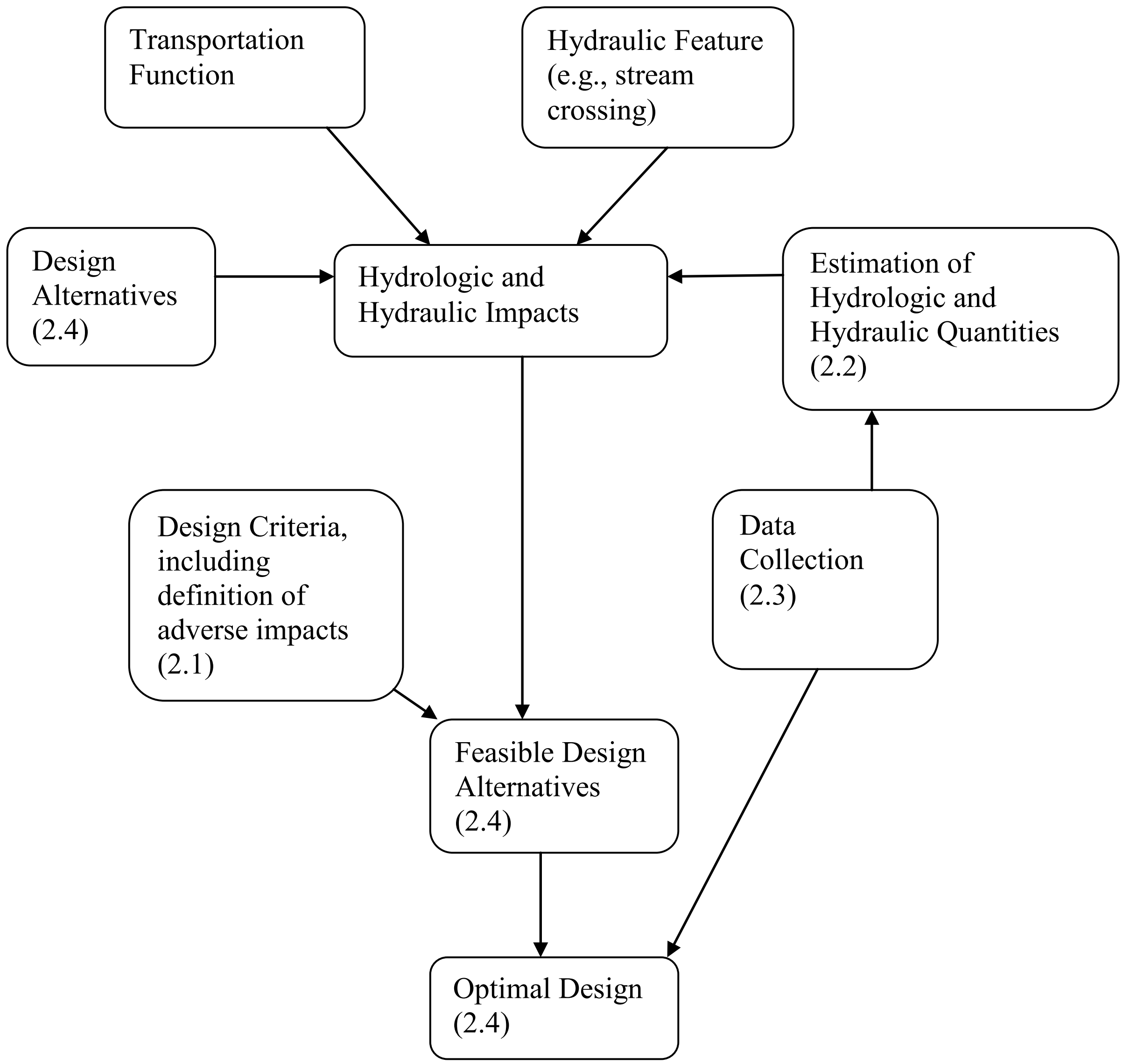


Figure 2.1. General Process Leading to the Design of Drainage Systems.

2.1 DESIGN CRITERIA

The hydrologic and hydraulic criteria TxDOT is to use for the design of its drainage systems may be dictated by the legal system, may be developed as agency policy based on the recommendations of others or its own experiences, or may be based on quantitative or qualitative risk assessment by the project's hydraulic engineer. Various criteria and reasons for the criteria are presented in TxDOT HDM (2011). The manual gives instruction for selection of design criteria based on quantitative and qualitative risk assessment, along with detailed forms listing the wide diversity of items to be considered or estimated by the engineer (Chapter 3); limits the design flood to the range of a two-year event to a 100-year event (Section 4-4); and provides a table of design annual exceedance probabilities (AEP) recommended for various drainage system components depending on the functional classification (i.e., principal arterial, local road, etc.) of the road, while noting that federal directives require interstate highways, bridges and culverts be designed for the 2 percent (50-year) flood event, and that all facilities must be evaluated at a 1 percent (100-year) check flood event (Section 4-6).

This section of the literature review first briefly covers risk assessment, which may result in stricter criteria than the minimum dictated by state or federal rules or TxDOT agency policies. Then it covers the legal system insofar as it may relate to design criteria TxDOT is to use for its drainage systems. Finally, this section reviews context-sensitive solutions (CSS), an approach for a more explicit incorporation of communal values into projects.

2.1.1 Local Risk Assessment

TxDOT HDM (2011) provides a discussion of how risk assessment, qualitative or quantitative, is a necessary element of the design process (Section 3-3), as well as detailed assessment forms. It also references the Least Total Expected Cost (Corry et al., 1981) as a method for quantitative risk assessment, in FHWA's HEC-17. Assessment almost invariably leads to the calculation of a trade-off between the cost of the project and risk of negative hydrologic and hydraulic impacts to human life and property, and may require an iterative process that alternates between designing and assessing impacts before arriving at a final design. An important criterion to include in this process is what maximum damage is allowed to occur for a 100-year check flood event. This value may be especially important in situations where the design flood is typically allowed to be of a much higher frequency. For example, a culvert for a minor arterial is listed in Table 4.2 of TxDOT HDM (2011) as having a *recommended* 10-yr design flood. The engineer must not assess risks only for the 10-yr design, but also for the 100-yr design, to ensure that backwater and overtopping effects are acceptable rather than catastrophic. TxDOT HDM (2009 and 2011) requires that all facilities be evaluated to the 1 percent AEP flood event.

The more refined the risk assessment tools are, the better the trade-off will be between project costs and adverse impacts, and the better the design criteria and allowable adverse impacts may be for the particular project of concern. Life cycle cost models such as that of Lee et al. (2006) may be considered as part of a risk assessment toolkit. The Hydrologic Engineering Center's Flood Damage Analysis software (HEC-FDA) may also prove helpful in more convenient risk assessment, especially for entities already utilizing HEC's other Next Generations (NexGen) software, such as HEC-HMS and HEC-RAS. HEC-FDA has been utilized in the literature (Ahmad and Simonovic, 2001; Carl, 2009). Greg (2008) presents a method for automating HEC-FDA's floodplain inventory. Rigorous risk assessment may be a time-demanding process. As TxDOT HDM (2011) suggests, the degree of risk assessment should be based on the cost of the project and the risks involved.

2.1.2 Legal Considerations toward the Development of Criteria

As hydraulics engineers participate in the design of TxDOT projects so as to minimize their adverse hydrologic and hydraulic impacts, they must consider various possible legal implications of these impacts. These implications may be helpful in the development of design criteria and in defining adverse impacts. This portion of the literature review therefore reviews the legal system and lawsuits between TxDOT and other entities, but is not intended as a substitute for seeking professional legal advice for particular projects.

2.1.2.1 Overview of the Legal System

Constitutional law is the "body of law deriving from the U.S. Constitution and dealing primarily with governmental powers, civil rights, and civil liberties" (Black's Law Dictionary, 1999). Constitutional law empowers Congress to establish agencies and to write laws that define the powers and limitations of those agencies. These agencies promulgate rules and regulations to achieve the purposes for which the agencies were created. The Supreme Court has the authority to void any legislation or agency promulgation that it finds to be contrary to constitutional law, the supreme law of the land.

The body of laws that create and define the powers of the governmental agencies, as well as the rules and regulations the agencies promulgate, is known as administrative law. Statutory law consists of any explicitly written law, including administrative law, but not including constitutional law. Only the Supreme Court may judge a statutory law as unconstitutional. Courts must apply statutory law to cases brought before them. However, the application of laws is not always clear for the variety situations that may arise in a complex and evolving society, and the courts must then develop a ruling based on its interpretation of the laws. Precedents and then traditions of interpretation are established, to form a body of rulings referred to as case law.

The above categories of law and the relationships between the categories at the federal level are mirrored at the state level. State law is subordinate to federal law.

2.1.2.2 Statutory Law at the Federal and State Levels

The National Flood Insurance Act of 1968 established the National Flood Insurance Program (NFIP), which is administered by the Federal Emergency Management Agency (FEMA). Cities, counties, and other communities voluntarily participate in the NFIP, and meet various requirements in exchange for its property owners receiving subsidized flood insurance coverage. One of these requirements, defined in Section 60.3 of Title 44, Chapter 60 of the Code of Federal Regulations (44 CFR 60), is that the community shall not permit encroachments to be constructed in a regulatory floodway unless hydrologic and hydraulic calculations show that for a flood having an annual exceedance probability (AEP) of 1 percent the base flood elevation (BFE) will not increase, or unless other conditions are met requiring special permission from FEMA. When certain conditions are met, or if the floodway is not yet classified as regulatory, a rise of 1.0 ft or greater may be allowed through the FEMA permitting process, as stated elsewhere in 44 CFR 60.3.

Another requirement for NFIP participating communities is that any construction in flood-related erosion-prone areas must be submitted for review to ensure that the construction does not exacerbate the erosive conditions (44 CFR 60.5). Communities may obtain technical assistance for such reviews from the NFIP State Coordinating Office, which in Texas is the Texas Water Development Board (TWDB). An increase in flow velocity exacerbates erosive conditions, and may be considered an adverse impact for TxDOT projects in such areas.

In 23 CFR 650 Subpart A, the Federal Highway Administration (FHWA) policies and procedures are prescribed "for the location and hydraulic design of highway encroachments on flood plains…" (650.101). One of those policies is "To be consistent with the intent of the Standards and Criteria of the National Flood Insurance Program, where appropriate" (650.104.g). The FHWA seeks to "restore and preserve the natural and beneficial flood-plain values that are adversely impacted by highway actions" (650.104.e), regardless of whether the floodplain is of an NFIP participating community. In particular, according to FHWA's *Procedures for Coordinating Highway Encroachments of Floodplains with FEMA,* "Encroachments which are outside of NFIP communities or NFIP identified flood hazard areas should be designed in accordance with 23 CFR 650A." Thus, the project should be designed with the same attentiveness to adverse impacts as it would be in a participating community, and the same standards should be utilized as far as is practicable.

Another federal law of concern to TxDOT is the Food Security Act, under which property owners receive financial incentives from the U.S. government for maintaining wetlands on their agricultural land, as discussed in the Iowa Drainage Law Manual (Andrle, et al., 2005). Ensuring that TxDOT projects do not deplete water in a wetland under the jurisdiction of the U.S. Department of Agriculture is thus another responsibility of TxDOT engineers.

Texas statutory law relevant to defining adverse hydrologic or hydraulic impacts includes that of Chapter 11 of the Texas Water Code (TWC). In particular, TWC Section 11.086, paragraphs (a) and (b) state

> (a) No person may divert or impound the natural flow of surface waters in this state, or permit a diversion or impounding by him to continue, in a manner that damages the property of another by the overflow of the water diverted or impounded.
> (b) A person whose property is injured by an overflow of water caused by an unlawful diversion or impounding has remedies at law in equity and may recover damages occasioned by the overflow.

Sections 311.005 of the Texas Government Code clarifies that TxDOT may be considered a "person" by including "government or governmental subdivision or agency" in its definition of "person." Exceptions to TWC Section 11.086(a) are those in which TxDOT exercises eminent domain, in which case it would still need to compensate the property owner if the damage is foreseeable, as will be discussed in Section 2.1.2.4.1 of this study. Additionally, under TWC Section 11.152, the diversion of relatively large volumes of water (greater than 5000 acre-feet per year) will trigger an assessment that could require mitigation of adverse impacts on the habitat, though such quantities of diversion may be unusual for TxDOT projects.

Table 2.1 lists examples of adverse impacts as defined in federal and Texas law. Additional discussion of federal and state law relating to adverse impacts may be found in TxDOT HDM (2011).

Table 2.1. Examples of Various Contexts and Their Impacts That Could Be Identified as Adverse in Statutory Law.

Context in which the hydrologic/hydraulic impact may be identified as adverse by statutory law	Hydrologic/ Hydraulic Impact	Relevant statutory law
Project encroaches upon regulatory floodway of an NFIP participating community	Increase in water surface elevation for 1% AEP flood	44 CFR 60.3 23 CFR 250 A
Project is in a FEMA flood-related erosion-prone area	Increase in water velocity	44 CFR 60.5 23 CFR 250 B
Project is near wetlands under the administration of the USDA	Decrease in water surface elevation	Food Security Act
Project may cause a diversion or impounding of water of concern for habitats or property	Increase in water surface elevation Decrease in water surface elevation Increase in velocity Change in flowrates	Any of the laws listed above TWC 11.086 TWC 11.152

2.1.2.3 Local Ordinances and the No Adverse Impact Approach

The trend in state drainage laws in the United States seems to generally be growing stricter regarding hydrologic and hydraulic impacts. According to a study prepared for the Association of State Floodplain Managers (ASFPM, 2008), the common-enemy doctrine has generally yielded to the rule of reasonable use which in turn is being augmented in some communities by a No Adverse Impacts (NAI) approach (Kusler and Thomas, 2007).

The common-enemy doctrine is the "rule that a landowner may repel surface waters as necessary (as during a flood), without having to consider the consequences to upper landowners. The doctrine takes its name from the idea that the floodwater is every landowner's common enemy." (Black's Law Dictionary, 1999) Reasonable use is the "use of one's property for an appropriate purpose that does not unreasonably interfere with another's use of property" (Black's Law Dictionary, 1999). The trend toward replacing the common-enemy doctrine with that of reasonable use is exemplified in the Page Motor Co. v. Baker ruling in Connecticut: "We now feel that the inflexibility of the old rule … should be modified so as to allow some reasonable latitude. By way of dictum, we are now inclined to adopt what some jurisdictions have termed the reasonableness of use rule" (Surface Water in Connecticut, 2010).

In general, "No Adverse Impact floodplain management takes place when the actions of one property owner are not allowed to adversely affect the rights of other property owners," and that impact "can be measured in terms of increased flood peaks, increased flood stages, higher flood velocities, increased erosion and sedimentation, or other impacts the community considers important" (ASFPM, 2008). This is in contrast with the "reasonable use" approach adopted by many states, in which a variety of relevant circumstances are to be considered in determining whether the use of one's property does not unreasonably interfere with another's use of property. The NAI approach may embody a quantitatively measured strictness not present in the rule of "reasonable use," though the particular NAI approach and the degree of strictness will vary among communities.

The NAI approach also provides communities with a framework for developing ordinances that are stricter than the minimal NFIP requirements for FEMA-participating communities, and more easily upheld in a court of law against developers (Kusler and Thomas, 2007). For example, while the NFIP requires under 44 CFR 60.3 that the "cumulative effect of the proposed development, when combined with all other existing and anticipated development, will not increase the water surface elevation of the base flood more than one foot," the City of Keene, New Hampshire, adopted an ordinance that "the cumulative effect of the proposed development, when combined with all other existing and anticipated development, will not increase the water surface elevations of the base flood at any point within the community." (Kusler and Thomas, 2007). Under the minimal NFIP requirements, the base flood elevation may, over time, increase by much more than 1 ft as FEMA floodplain maps are periodically redrawn with new (sometimes higher) floodplain reference elevations due to development that has occurred since the previous mapping publication. The City of Keene's ordinance would not permit this. The New Hampshire Supreme Court has upheld this ordinance because it was clearly established in the public interest (Kusler and Thomas, 2007).

How well NAI ordinances might be used by a plaintiff against TxDOT may be worthy of further investigation. An important factor is the extent to which Texas has waived its federally granted sovereign immunity, as discussed in the following section. One must note, however, that NAI ordinances may also better protect TxDOT infrastructure from private interests or municipalities who irresponsibly redirect or back up flows, as discussed in the last three paragraphs of Section 4.4.1.

2.1.2.4 Reasons for Drainage- or Flooding-Related Lawsuits against TxDOT

An examination of the various drainage- or flooding-related lawsuits brought against TxDOT may help TxDOT anticipate situations in which legal problems may occur, and to discern whether remedies lie in a more rigorous following of statutory law, in adopting an NAI approach, or in other means.

The Eleventh Amendment of the United States Constitution grants sovereign immunity to states. This immunity protects states and their agencies from being held liable for wrongdoing when sued. Even if plaintiffs otherwise have claims against the agency that appear reasonable, the case may be quickly dismissed because of the immunity. However, through state constitutions, decades of political will and legislation, and the development of case law, states have typically waived some of this immunity to move closer toward a balance that allows them to achieve various tasks in the public interest without being bogged down in lawsuits, as long as it is reasonably careful in its work. Two ways in which Texas has waived sovereign immunity and that are of interest to TxDOT are for inverse condemnation and tort claims. Lawsuits brought against TxDOT will typically fall into one of these categories of claims. In the following two sections, the LexisNexis Academic database was used for finding and interpreting lawsuits involving TxDOT. Only cases that were appealed are covered by the database and are included in this review. Cases are reviewed that tended to be the most difficult to resolve and hence collectively most precisely define the requirements for plaintiff success in lawsuits against TxDOT. Furthermore, a review of cases in trial courts would require visiting individual county courthouses in a time-consuming search that would yield decisions that carry little or no weight in the development of case law. TxDOT's own in-house records may be worth reviewing for such cases as well as those settled out of court.

2.1.2.4.1 Inverse Condemnation Claims

Condemnation is "the determination and declaration that certain property (esp. land) is assigned to public use, subject to reasonable compensation to the landowner" (Black's Law Dictionary, 1999). As a state agency, TxDOT may exercise its right of eminent domain by taking (condemning) privately owned land that is needed for its projects, as long as the landowner is paid for the land. Inverse condemnation is an action brought by a property owner for compensation from a governmental entity that has taken the owner's property without bringing formal condemnation proceedings (Black's Law Dictionary, 1999). The taking of the property does not necessarily mean that the boundaries of the TxDOT project overlap some or all of the property, but can also mean that the property was damaged by the project, as when, for example, the project causes more frequent flooding of the property.

Under the Texas Constitution, Article I, Section 17 (reproduced as Appendix A), sovereign immunity is waived in cases of inverse condemnation. In this literature review, we limit our review of inverse condemnation cases to those associated with flooding or drainage, but we are exhaustive in the listing of such cases to demonstrate the limited potential of the body of such cases for informing TxDOT regarding establishing design criteria or defining adverse impacts. The cases are also discussed to convey an understanding of particular legal issues. Although the discussion of the particular cases found in the literature review may not explicitly contribute to developing design criteria or defining adverse impacts, they do contribute to an understanding of the legal milieu in which such criteria and definition would be established. Such an understanding is a necessary part of efforts to advance design criteria and definitions of adverse impacts.

In 1994, in a lawsuit which TxDOT inherited from the State Department of Highways and Public Transportation, landowners John H. Biggar and others were awarded $1.5 million in damages (State v. Biggar, No. D-3755). The agency had been using an easement on the Biggar tract in the City of Austin for flood drainage. When Biggar and others had requested an easement exchange to allow for landowners' development plans, the agency approved, but then later retracted, causing the landowners' development deadlines not to be met while the agency proceeded with further, conflicting development of the area. The value of the landowners' properties was drastically reduced due to the agency's retraction of the initial approval, and then the agency paid the landowners' a relatively small sum for an additional easement it acquired through eminent domain on the now-devalued land. The Court of Appeals for the Third District of Texas held that the Texas Constitution, Article I, § 17 required the award of damages when the state denied an otherwise routine easement exchange in order to lower the value of property it later acquired through eminent domain. This case is noteworthy as an instance in which TxDOT was sued apparently without TxDOT (or its predecessor agency) having violated any statutory law or case law in existence at the time. However, as the agency was aware of the property owners' progress and plans but "pulled the rug out from under them," the problem seems to have been avoidable if the agency had employed a common sense understanding of fairness, even if it did not anticipate the court's interpretation of the Texas Constitution.

The property owners' actual use or demonstrated progress toward actual use of land carry weight in a court of law, but hypothetical future possibilities for use seem to carry less weight. In 1998, a TxDOT project in Galveston County, which involved a drainage easement, reduced but did not eliminate access to undeveloped land owned by George M. Delaney and Patricia Ann Delaney (State v. Delany, No. 04-0628). They brought an inverse condemnation suit against TxDOT. The court ruled in favor of the Delaneys. However, after an appeal, and then a petition for review, it was ruled in April 2006 that, although the options for accessing the property were reduced, the property was still fully accessible. Also, as the land was undeveloped and the Delaneys had merely hypothetical ideas regarding its development, TxDOT could not be sued for eliminating options the Delaneys might one day wish to exercise in developing the land.

In a more recent inverse condemnation lawsuit, property owners A.P.I. Pipe & Supply, LLC and Paisano Service Company, Inc., sued TxDOT and the City of Edinburg for large quantities of soil TxDOT removed from an easement on the property owners' land (Tex. DOT v. A.P.I. Pipe & Supply, LLC, NUMBER 13-07-221-CV). TxDOT had removed the soil to construct a drainage channel through the easement, and then used this soil to fill an embankment for its highway construction project. County Court at Law No. 2 of Hidalgo County ruled in favor of the plaintiffs. TxDOT and the City of Edinburg appealed. In August 2010, the 13th District Court of Appeals, Corpus Christi-Edinburg, upheld the lower court's ruling in favor of the property owners. TxDOT and the City of Edinburg petitioned for review in January 2011. A review of the case suggests that the conflict could have been avoided with more careful wording in the easement, or with more careful filing procedures.

The above three inverse condemnation suits are related to easements used for drainage. Inverse condemnation suits may also be based on claims that have nothing to do with easements, but rather with the flooding and therefore devaluing of property. However, case law seems to interpret the waiver of sovereign immunity in the Texas Constitution to mean that the claimant must establish that the governmental entity ***intentionally*** performed certain acts that resulted in ***a taking of the property***. (LexisNexis, Headnote #2, State v. Agnew). The requisite ***intent*** is present when a governmental entity (a) knows that a specific act is causing identifiable harm, or (b) knows that the harm is substantially certain to result (LexisNexis, Headnote #2, State v. Agnew). The intent of the Texas Constitution, Article I, Section 17 is not to protect property owners from state agency mistakes or negligence, but to protect them from state agencies deliberately taking their land for a public project without compensation.

In November 2002, in Aransas County, the property of John R. Agnew et al. was flooded as TxDOT was constructing the State Highway 35 Bypass. These property owners subsequently brought forth a claim that TxDOT had diverted and impounded surface waters, and had also pumped water from the opposite side of the highway, such that their properties were flooded (State v. Agnew, NUMBER 13-05-00143-CV). This assertion was not refuted by the court. However, when the claimants asserted that they were therefore entitled to compensation for damages, TxDOT responded with a "plea to the jurisdiction" (i.e., that an inverse condemnation claim was not established and therefore TxDOT's sovereign immunity is not waived, and that the court therefore has no jurisdiction over the matter). The court stated that claimants did not allege that TxDOT ***knew*** that the flooding was substantially certain to occur (LexisNexis, State v. Agnew), and the plea to the jurisdiction was effective as the claimants failed to substantiate an inverse condemnation claim. This opinion was filed by the 13th District Court of Appeals in June 2006.

In October 2002, in Harris County, after TxDOT constructed a concrete-lined drainage ditch along Highway 59, and included a rip-rap dam as part of the drainage system apparently to prevent downstream flooding, properties of Bernard J. Toomey et al. were allegedly flooded as a result (Toomey v. Tex. DOT, NO. 01-05-00749-CV). Damage included that of cars parked on an automobile sales lot. The County Civil Court at Law, No. 3, Harris County ruled in favor of TxDOT. The plaintiffs appealed, but the 1st District Court of Appeals, Houston, upheld the ruling of the trial court. The reason for the ruling in favor of TxDOT is that inverse condemnation was not established. Even if the impact could be firmly established by a rigorous hydraulic study of pre- versus post-project conditions, the court would have still likely sided with TxDOT. The plaintiffs only demonstrated that the flooding occurred once, whereas multiple floodings after the project as opposed to no floodings before the project would have allowed for at least suspecting that TxDOT would have known the project had a flooding effect on the property. If TxDOT had been aware, the flooding could have been considered a "constitutional taking" of the property, for which compensation would be required. The opinion was issued in April 2007.

Interestingly, in another lawsuit in Harris County, Edward A. and Norma Kerr et al. (approximately 360 plaintiffs) claimed that TxDOT construction of feeder lanes on Beltway 8 and reconstruction of portions of Highway 290 in the 1980s and 1990s increased stormwater runoff that "detrimentally impacted" plaintiffs, who were downstream of these activities (Kerr v. State DOT, NO. 01-00-01269-CV). These plaintiffs eventually formulated an inverse condemnation claim that, although the flooding of their properties was not necessarily intentional, the act that was clearly intentional (i.e., the Beltway 8 and Highway 290 projects) necessarily caused the flooding. This opinion was issued in April 2001 by the 1st District Court of Appeals, after a trial court had ruled in favor of TxDOT. It is not clear how much weight this opinion, which may provide an interpretation of Article I, Section 17 that is more favorable toward property owners than do the later opinions of 2006 and 2007, carries in case law.

In general, an inverse condemnation case against TxDOT for flooding is more difficult for a property owner to win than would be a damages lawsuit against a private entity. In inverse condemnation cases, the waiving of sovereign immunity occurs only with intentionality and other conditions necessary for a "constitutional taking" of the property. The only drainage-related inverse condemnation plaintiffs with success in this literature review are Edward A. and Norma Kerr et al. In addition to the previously mentioned plaintiffs who failed in such cases, the following failed against TxDOT: Dolores Ahart et al. versus TxDOT (

NO. 14-05-00027-CV) in Harris County, with opinion filed in August 2006; Brandywood Housing, LTD, versus TxDOT (Brandywood Hous., Ltd, v. Tex. DOT, NO. 01-00-00049-CV) in Harris County, with petition for review denied in July 2002; and Richard Evatt et al. versus TxDOT (Evatt v. Tex. DOT, No. 11-05-00031-CV) in Taylor County, with opinion filed in May 2006. This list is not exhaustive.

In theory, an inverse condemnation claim could be brought against TxDOT should a TxDOT project lead to the depletion of water from wetlands on otherwise agricultural property, and should TxDOT fail to reimburse the landowner for financial benefits that would have been received from the U.S. government for maintaining the wetlands. Such an inverse condemnation claim against TxDOT was not found in the literature.

Though inverse condemnation cases for flooding seem rarely won by plaintiffs, plaintiffs can ask the Texas Legislature to waive sovereign immunity for any particular case. No such request was found in this literature review.

2.1.2.4.2 Tort Claims

The Texas Tort Claims Act, enacted by the Texas Legislature in 1969, waives sovereign immunity for three areas: 1) injury caused by an employee's use of a motor-driven vehicle; 2) injury caused by a condition or use of tangible personal or real property; 3) claims arising from premises defects (LexisNexis, Villegas v. Tex. DOT). The first area is not relevant to drainage issues. The second and third areas, in relation to drainage issues, require that the plaintiff's claims are in response to the presence of water encountered in the TxDOT ROW, leading to an accident-induced injury or other loss. The plaintiff must demonstrate certain special conditions to succeed, such as that *excessive* ponding occurred in the driver's lane due to a *special* defect, and that TxDOT knew of the defect but was negligent in warning. While reviewing litigation having to do with alleged drainage problems on the travel lanes may not be an anticipated objective of the present study (which considers the possible drainage impacts of TxDOT projects only on the *surrounding* environment), the structural design that carries water off the pavement is inter-related with the structural design that ultimately carries the runoff to beyond the ROW. Also, a review of particular tort cases, though not necessarily having explicit implications for particular definitions of adverse impacts, enhances understanding of the legal milieu related to drainage issues, a milieu which must be considered when defining adverse impacts. Noteworthy also is that the District Hydraulics Engineer is not formally precluded from addressing the hydraulics problems that may occur in the travel lanes or elsewhere on the roadway, and indeed may be the most qualified person in the District to do so. A review of such tort cases appears in Appendix B for the interested reader.

2.1.2.4.3 The Potential for Other Claims

The legal landscape evolves through the development of case law traditions and legislation. The Texas Constitution is subject to interpretation, and the courts have developed a tradition (case law) that some claims provide an interpretation of Article I, Section 17 that is too favorable to state agencies. In 2007, the Texas Legislature attempted to enact a bill, House Bill 2006, that would generally require greater re-imbursement to property owners when state agencies exercise eminent domain (Tinsley, 2007). Although the bill was vetoed by Governor Rick Perry, one can see how law tends to shift with time. Like other state agencies, TxDOT is in an evolving legal environment.

TxDOT is also faced with the challenge that any plaintiff may appeal to the legislature in their particular case to waive sovereign immunity, even if the claim is neither of inverse condemnation nor tort. This potential may be greatest when the plaintiff is a community which has carefully developed a "No Adverse Impact" approach.

For these reasons, although sovereign immunity helps TxDOT and other state agencies to move forward with their projects in a relatively efficient manner on behalf of the public welfare, the immunity provided in the past will not necessarily be provided to the same extent in the future.

2.1.2.5 Reasons for Drainage- or Flooding-Related Lawsuits against State DOTs Other Than TxDOT

The key element determining the types of lawsuits that may be brought against other state DOTs is the waiving of sovereign immunity through their state Constitutions or Legislatures. The Constitution of the State of Iowa, for example, like the Texas Constitution, waives sovereign immunity for inverse condemnation, as referenced in the Iowa Drainage Law Manual (Andrle et al., 2005). Such waiving must be considered when reviewing the practices of other state DOTs with those of TxDOT.

2.1.3 Other Considerations toward Development of Design Criteria

Public agencies may adopt a variety of dispositions in relating to the general public. An agency may seek merely to satisfy legal requirements. The Texas Board of Professional Engineers' code demands more than this of engineers. It demands engineers to be competent, objective, and truthful as they protect the public (Paragraphs 137.55, 137.57, and 137.59 of TBPE's Texas Engineering Practice Act and Rules Concerning the Practice of Engineering and Professional Licensure – March 10, 2011, effective date). This report is part of TxDOT's ongoing effort to better serve the public while exceeding mere legal requirements.

A disposition encouraged by AASHTO's Center for Environmental Excellence (http://environment.transportation.org) is to view legal requirements as a mere starting point, to strive for what is truly best for the general public, and to even be willing to re-shape oneself as the needs of the public change or are better understood. This preferred disposition requires an ongoing dialogue with the public regarding particular projects of the agency, and public participation in the shaping of those projects. AASHTO's Center for Environmental Excellence affirms context-sensitive solutions (CSS), encourages a collaborative approach so that the projects better fit into the community and environment.

One of the projects that AASHTO identifies as a CSS is TxDOT's Safety Rest Area Program (http://environment.transportation.org/environmental_issues/context_sens_sol/case_studies). In this project, TxDOT achieves its safety goal by providing rest areas with safety tips, maps, and Internet access, while at the same time preserving community heritage and regional flavor through architectural aesthetics, protection of natural resources, and promotion of environmental sensitivities such as rainwater harvesting. Exhibits at each rest area interpret the history, culture, and the natural environment of the surrounding areas.

Another example of a CSS is that of the Snoqualmie Pass East Project of Washington DOT, where WSDOT worked with 12 agencies representing the community to integrate the project into the area's ecosystem and the state's economy, leading to context-sensitive designs on wetlands mitigation, wildlife monitoring, and stormwater.

A CSS which explicitly re-shapes the agency itself is that which is occurring in California's Department of Transportation (Caltrans). Caltrans, by mandate of the state government, is adopting policies, directives, guidance documents, funding mechanisms, and training programs to foster early and continuous collaboration with stakeholders, balance transportation needs and community values, and promote interconnected, multi-modal transportation systems.

These and dozens of other CSSs are recognized and described at the AASHTO Center for Environmental Excellence website (http://environment.transportation.org).

2.1.4 Conclusions Regarding Development of Design Criteria

Statutory law and TxDOT policy are reviewed or presented in TxDOT HDM (2011) to provide various design criteria. Case law, because of sovereign immunity and the limitations of its inverse condemnation and tort waivers, is not to be relied upon for providing strong guidance for design criteria to be used by TxDOT. Quantitative and qualitative risk assessments provide the flexibility needed to set the best design criteria for each site. The list of items to be included in such assessments and the weights given to each may be subjective. Inclusion of the larger community through context-sensitive solutions may be a means for reflecting values of the larger community in the development of design criteria.

2.2 ESTIMATION OF HYDROLOGIC AND HYDRAULIC QUANTITIES

2.2.1 Descriptions of Model Types and Software

A clarification of terms may be helpful to a discussion of methods for estimating flood peaks and other hydrologic and hydraulic quantities. A mathematical model is an equation or set of equations that describe a physical phenomenon. Much of the software available through the Federal Highway Administration or other government agencies is open source, i.e., the source code expressing the mathematical model and directing calculations and output can be readily requested, opened and read by the user.

This literature review distinguishes between open source and proprietary software because open source software provides three distinct advantages: 1) It is free of charge, while maintaining reputability when provided by an authoritative entity, such as the FHWA; 2) Accessibility to its code allows for the hydraulic engineer to thoroughly see the models and techniques used to generate the estimated quantities; and 3) As is the case with clear, handwritten work, the transparency provided by open source software could prove important in a court of law. However, software is not superior merely by being open source. Propriety software of superior performance, especially if endorsed or used by government agencies such as FEMA, may in some cases prove to be a desirable alternative. TxDOT may seek legal counsel as part of its decision-making process regarding software.

Models may be either hydrologic or hydraulic. Hydrologic models calculate flow volumes and flowrates, sometimes as a function of time such that a hydrograph is generated. Hydraulic models have the capacity of estimating flow velocities and water surface elevations. Typically, results from a hydrologic model are used as input into a hydraulic model. For example, hydrographs generated from the hydrologic model HEC-HMS (www.hec.usace.army.mil/software/hec-hms) or by Natural Resources Conservation Services (NRCS) methods can be used as input into the hydraulic model HEC-RAS.

Hydrologic models are typically either semi-distributed or two-dimensional (a.k.a. fully-distributed). In a semi-distributed model, the basin or drainage area of concern is divided into subbasins, and the degree of subdividing is determined by the modeler. The hydrologic output is then computed at the outlet of each subbasin. In a two-dimensional model, the basin is divided into a grid, and the resolution of the grid cells is determined by the modeler. The hydrologic output is generated for each cell. An example of a commonly used semi-distributed hydrologic model is that of the HEC-HMS software, which is open source. Also, when NRCS methodology or the rational method is applied to a nest of subbasins (each with a different curve number or rational coefficient), semi-distributed hydrologic modeling is being performed. An example of two-dimensional hydrologic modeling is that provided by the Gridded Surface Subsurface Hydrologic Analysis GSSHA software (chl.erdc.usace.army.mil/gssha). It is freely available through the Army Corps of Engineers (USACE), but is not yet open source due to the current research contract between the developer and USACE. XP-SWMM (http://www.xpsoftware.com/products/xpswmm) is an example of widely used propriety software that incorporates aspects of two-dimensional hydrologic modeling. Versions 8.52 and higher are listed as "acceptable" by FEMA (http://www.fema.gov/plan/prevent/fhm/en_hydro.shtm). Two-dimensional hydrologic models are generally of greater accuracy than semi-distributed models because grid cell sizes may be made much smaller than realistic subbasin sizes, and therefore less lumping of spatially distributed characteristics (soil type, ground slope, land use, etc.) occurs. Lumping is undesirable because thresholds and nonlinearities in realistic mathematical representations of basins prevent a useful "averaging" of subbasin characteristics. The more extensive the lumping is, the more unlikely it will be for the model to match observed output for storm volumes of different magnitudes.

Semi-distributed hydrologic models such as that of HEC-HMS software may be run at the daily, subdaily, subhourly, or minute time-steps, depending on the particular software. The finer time resolutions require finer spatial resolutions in order to be worthwhile. Semi-distributed models are therefore often run at the daily time-step. Two-dimensional hydrologic models are to be run at a much finer time-step, typically of a sub-minute scale, to effectively represent the passage of flow between the relatively small grid cells. Also, the spatial and temporal distribution of the storm, available as, for example, NEXRAD MPE data from the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/rsad/mpr.html#data), may be input as an electronic file for two-dimensional models.

Hydraulic models may be either one-dimensional or multi-dimensional, and the dimensionality refers to the channel flow. For one dimensional flow, a single value of velocity and depth of flow is provided for each point along the length of the channel. The multi-dimensional hydraulic modeling of primary relevance to TxDOT is two-dimensional. In such modeling, variations in velocity across a channel may be calculated at any cross-section of concern. Both one-dimensional and two-dimensional hydraulic models require channel cross-sections as input, but a two-dimensional hydraulic model requires greater expertise and time to implement, and also requires the output of more sophisticated hydrologic modeling as input.

2.2.2 Particular Models and Software

TxDOT HDM (2011) presents in detail a variety of hydrologic models (as well as charts and methodologies incorporating the models) for estimating stormwater runoff volume, peak flow, time of concentration, and generating hydrographs. Generally, these may be used as semi-distributed or entirely lumped (one set of parameters for the entire drainage area or basin), depending on the level of detail sought by the modeler. The AASHTO *Highway Drainage Guidelines* (2007) is much less thorough in its coverage of mathematical models than is TxDOT HDM, but does include descriptions of 10 software packages for hydrologic modeling, all of which are lumped or semi-distributed: HYDRAIN (including HYDRO for rural areas and

HYDRA for urban), HEC-1/HEC-HMS, NRCS TR-20, Stormwater Management Model (SWMM), Stanford Watershed or Hydrocomp (HSP), Penn State Urban Runoff, Massachusetts Institute of Technology Catchment (MITCAT), USACE STORM, Illinois Urban Drainage Area Simulator (ILLUDAS), and USGS "Dawdy."

The Slope Conveyance Method and the Standard Step Backwater Method, both of which are described in TxDOT HDM, are examples of one-dimensional hydraulic modeling that may be easily executed on a spreadsheet. They may also be executed using Hydraulic Engineering Center – River Analysis System (HEC-RAS) software. Geopak Drainage (www.bentley.com) may also be used for one-dimensional modeling, though the latter is proprietary software.

Two-dimensional hydraulic modeling may be advantageous over one-dimensional modeling for a variety of situations. For example, the differences in the "average" velocity yielded by HEC-RAS and the maximum velocity found along the cross-section may be particularly high at channel bends. Larsen et al. (2011) found that FESWMS (Finite-Element Surface Water Modeling System [Froehlich, 1989]) successfully predicted velocities that would cause observed scouring at a bridge located at such a bend in the Big Sioux River in South Dakota, whereas HEC-RAS did not. In regard to water depths, Cook and Merwade (2009) found that variations in flood inundation maps generated for the Strouds Creek basin in North Carolina by use of FESWMS were smaller than they were for such maps generated by HEC-RAS, as various factors were better accounted for by the two-dimensional hydraulic modeling. FESWMS has also been used in the design of constructed wetlands in South Florida (Von Zweck and Bushney, 2004). Other two-dimensional hydraulic modeling software includes TUFLOW Flood and Tide Simulation Software (www.tuflow.com), which is proprietary, and Adaptive Hydraulics Modeling system (ADH, (https://adh.usace.army.mil/), which is provided by the Army Corps of Engineers, but the source code is not yet available.

Two-dimensional modeling is more demanding in regard to data input (including the output of more sophisticated hydrologic modeling to be used as hydraulic modeling input) and hydraulics engineering experience. For larger, more complex drainage areas the task of adjusting the two-dimensional model to realistically match the natural phenomena becomes quite challenging. Due to resource limitations at the District level, TxDOT HDM (2011) recommends contacting the Design Division's Hydraulics Branch for consultation regarding two-dimensional modeling.

Examples of less commonly used models or software include a genetic algorithm (i.e., one that searches for an optimal solution by randomly selecting various design parameter values, but having that random selection process influenced by results of previous values) used to define the most economical combination of stormwater inlet type, size, and location subject to maximum width of gutter spread (Nicklow and Hellman, 2004); a spreadsheet-based design optimization of roadside infiltration for stormwater runoff from highways (Pack et al., 2004);

and a spreadsheet-based model to estimate the annual surface runoff volume reduction due to a vegetative buffer strip (Pack et al., 2005).

2.2.3 Selecting Models and Software in the Context of Uncertainties

In addition to the errors in estimation due to aggregating data, especially in lumped and semi-distributed models as opposed to higher resolution two-dimensional models, another source of error is the assumption that the soil is initially saturated when modeling a particular event. While conservative estimates may often be recommended, this assumption may lead to results that are overly conservative. Continuous simulation (i.e., simulating stream flow for a relatively long time period that includes multiple storms separated by dry periods) may be preferred (NCHRP, 2006).

Model parameters, which typically include the slope of the ground, the Manning coefficient, etc., are generally not known with complete accuracy at any given point, let alone for an entire drainage area. Uncertainties in parameter values, even before aggregation occurs, contribute to uncertainties in simulated values. Realistic parameter estimates based on a match between simulated and observed stream flow values may require continuous simulation over a lengthy time period.

Although continuous simulation over lengthy time periods may be helpful in reducing uncertainties associated with initial soil moisture assumptions, parameter estimates, aggregation, and other inaccuracies, such simulation is only useful when it can be compared against a continuous observed stream flow record for calibration. Such records are typically unavailable for TxDOT projects.

Another obstacle in modeling is the challenge of choosing a model. A literature review is somewhat helpful. HEC-HMS and HEC-RAS are two common software choices, as indicated by their appearance in hundreds of conference and journal publications, including recent Tier I journal articles (e.g., Cook and Merwade, 2009). However, model comparisons in the literature can easily become outdated as earlier versions of software are replaced with improved versions. More recent comparisons may be for models which have failed to enjoy widespread usage and/or may be relevant in a very limited context, and even then none of the models may demonstrate clear superiority (e.g., Tsirinitz and Sidan, 2007).

In light of the difficulties in selecting models and reducing uncertainties in model estimates, a reasonable approach is to select respected models and become familiar with the contexts in which they underestimate and overestimate, so that engineering judgment may be applied. Such judgment is perhaps the most valuable asset in preventing overly conservative design and in reducing the construction costs of projects, while also reducing the risks of underdesign due to failing to perceive subtle but substantial contributions to flow. This much-needed judgment may develop within engineers who frequently and over a long-term basis involve themselves directly in the hydrologic and hydraulic aspects of projects by applying the models. As an institution invests in personnel in resources such that sound hydrologic and hydraulics engineering judgement becomes established throughout a diversity of regions, best practices may increasingly emerge and complications and wasteful expenses be avoided. For example, the Harris County Flood Control District (HCFCD) found that the methodologies that had been commonly used in that county (the Rational Method; Johnson and Sayre USGS curves and generalized regression equations; discharge-area curves developed by Turner Collie and Braden, Inc.; and the TR-55 SCS Method) showed a wide variation in computed peak discharges, even for similar watershed and channel conditions. This led to confusion and problems with design and construction, and the eventual development of a consistent methodology to standardize hydrologic analysis and design of open channel drainage facilities (HCFCD Hydrology and Hydraulics Guidance Manual, 2009). It now requires, for example, that if the drainage area is greater than 640 acres, the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) software be used (HCFCD Policy, Criteria, and Procedure Manual, 2010), and that the Green and Ampt option and the Clark's Unit Hydrograph option must be selected unless HCFCD is consulted in advance (HCFCD Hydrology and Hydraulics Guidance Manual, 2009). For areas of less than 640 acres, Site Runoff Curves equations are to be used to estimate peak discharges, and the Small Watershed Hydrograph Method with a set of specified equations is used to generate hydrographs, with all equations clearly listed (HCFCD Policy, Criteria, and Procedure Manual, 2010).

As software progresses and electronic spatiotemporal data becomes more accessible, and TxDOT invests in personnel to develop engineering judgement regarding the usage of such software and data, TxDOT may more accurately estimate hydrologic and hydraulic quantities and reduce costs associated with uncertainties.

2.3 DATA COLLECTION

Depending on the models and/or software used, data to be collected or used may vary, as discussed in Sections 4-5 and elsewhere in TxDOT HDM.

For software such as HEC-HMS and HEC-RAS, data must be electronic format for convenient input. The Natural Resource Conservation Service provides digital elevation models (DEM) of 30 m and 10 m horizontal resolution and SSURGO and STATSGO soil data at http://datagateway.nrcs.usda.gov. The National Climatic Data Center provides precipitation and meteorological data at at http://www.ncdc.noaa.gov/oa/ncdc.html. The U.S. Geological Survey provides stream flow data at http://waterdata.usgs.gov/nwis/sw, as well as DEMs, land cover data, orthoimagery (photograph-like aerial images of the land) and other relevant data at http://seamless.usgs.gov. HEC-GeoHMS and HEC-GeoRAS may simplify the process of incorporating data into the HEC-HMS and HEC-RAS models.

In general, higher spatial and temporal resolutions provide more realistic model simulations. For example, Light Detection and Ranging (LIDAR) digital elevation models of 6 m horizontal resolution have been used as input into HEC-RAS for a reach of the Brazos River in Fort Bend County, Texas, to yield a different and presumably more accurate 100-year inundation map (Cook and Merwade, 2009).

Greater spatial resolution than is provided by most rain gauge networks is especially helpful in improving model simulations. The variability in rainfall between gauges is not easily predicted, and may profoundly impact the estimation of model parameter estimates and the capacity to predict the impact of future storms, even if the average of the rain gauge measurements over multiple years exactly matches the true rainfall for the basin over those years, because of thresholds and non-linear relationships in hydrologic models (Joseph, 2011).

Next Generation Weather RADAR (NEXRAD) data, which is at a 4 km x 4 km resolution, have been incorporated into a HEC-HMS/RAS model of the San Antonio River Basin and may serve to help define boundary conditions for local studies within the basin, and as a prototype for modeling other basins in Texas and elsewhere (Knebl et al., 2005).

2.4 DESIGN ALTERNATIVES AND OPTIMAL DESIGN

The drainage system is designed to mitigate adverse hydrologic and hydraulic impacts due to TxDOT roadway projects. These impacts are due to runoff from the roadway as well as the roadway's potential to divert and impound water approaching it from beyond the ROW.

Inevitably, water quality issues arise due to runoff from the roadway. Though these issues are not of direct concern for this present work, water quality and water quantity issues are seldom addressed in isolation from each other. Therefore, the literature was reviewed to consider what is favorable for addressing water quality that simultaneously addresses water quantity. Then the literature was reviewed explicitly for drainage structures, i.e., those structures that control stormwater from the roadway as well as stormwater and stream flow approaching the ROW from beyond it.

2.4.1 Best Management Practices (BMPs) That Also Address Water Quantity Impacts

The term "best management practice" (BMP) for stormwater management arose in response to the National Pollutant Discharge Elimination System (NPDES) established through the Clean Water Act in 1987. The term is popularly used to refer to anything from street sweeping to constructed wetlands, regardless of whether a particular management measure was the "best" management practice for the site conditions and constraints (NCHRP, 2006). However, in this literature review, we seek only those structural practices that have earned favor through the test of time, or seem promising.

Structural BMPs must not be considered merely as individual entities, but as components of a system. Indeed, one of the major developments in recent years regarding the system itself is the formalization of a decentralized approach to stormwater management, i.e., instead of having large volumes of stormwater collected (and treated) at a single outlet, have infiltration and storage runoff measures that are dispersed throughout the landscape, with the goal of matching runoff volumes and peaks to those of predevelopment conditions (NCHRP, 2006). This decentralized approach was first formalized in the late 1990s by the Department of Environmental Regulation of Prince George County, Maryland (1999), which referred to it as low-impact development (LID). LID is more easily implemented in areas of relatively low activity, but efforts are being made to make the approach more applicable to high-volume roads, with guidelines such as the following (NCHRP, 2006) for integrating various structural BMPs into a decentralized system:

Grade to encourage sheet flow and lengthen flow paths.

Maintain natural drainage divides to keep flow paths dispersed.

Disconnect impervious pavement areas from the storm drain network, allowing runoff to be conveyed over pervious areas prior to entering a centralized conveyance system.

Preserve the naturally vegetated areas and soil types that slow runoff, filter out pollutants, and facilitate infiltration.

Direct runoff into or across vegetated areas to help filter runoff and encourage recharge and evapotranspiration.

Provide small-scale distributed features and devices that help meet regulatory and resource objectives.

Regardless of the system of structures (such as drainage channels, culverts, vegetative filter strips, etc.) under consideration, the design is achieved through the use of mathematical models (such as Manning's Equation, and systems of equations) that are commonly incorporated into modeling software, as previously discussed.

Constructed wetlands, wetland swales, and proprietary structures may merit special consideration as potential BMPs.

Constructed wetlands and wetland swales can reduce adverse hydraulic and hydrologic impacts while mitigating pollution, and perhaps even enhancing the ecosystem. Though they generally offer the advantage of a better quality of water that ultimately enters the neighboring, naturally occurring bodies of water, the impact on wildlife that relies on the new structure may be less clear, suggesting limits to their applicability. In France, six highway stormwater detention ponds, dug along existing highways and simply intended for the detention of water, were quickly colonized by aquatic life, and reveal the need for chemical contamination of the ponds to be carefully reviewed and the problems of use by wildlife to be addressed (Scher et al., 2004). The prevention of short-circuiting is essential to the contaminant-reducing properties of constructed wetlands, and may require two-dimensional hydraulic modeling (Von Zweck and Bushney, 2004). Constructed wetlands and wetland swales may not be as effective as their dry counterparts of the same volume in reducing total storm volume runoff (Winston et al., 2010a; Winston et al., 2010b, NCHRP, 2006), and may not appear as the most cost-effective option from a strictly hydrologic and hydraulic perspective.

Proprietary structures are used to address stormwater quantity and quality issues, particularly in crowded urban areas where they are installed underground (NCHRP, 2006). In the absence of a national or state standard for evaluating proprietary devices, the Metropolitan St. Louis Sewer District developed a system for approving such devices for specified use levels based on certified performance (Hoskins and Buechter, 2009).

2.4.2 Drainage Structures

A current comprehensive listing and description of traditional drainage structures is provided by the American Association of State Highway and Transportation Officials' (AASHTO) *Highway Drainage Guidelines* (2007). Structures for surface runoff begin most simply with a permanent vegetative cover to reduce runoff. For runoff not prevented by the cover, open channels may be lined with concrete, vegetative cover, rip-rap, or flexible lining, and may include grade control structures to permit milder channel slopes. Shoulder drains guide water from elevated pavement to the toe of the embankment slope. Culverts may be accompanied by a stilling basin at the outlet. Revetments are placed along stream banks or highway embankments to protect against damage by stream or flood currents. Detention and retention facilities reduce the peak stormwater flow, and recharge facilities provide the additional advantage of replenishing the groundwater. Stormwater pumping stations are necessary when water must be removed but cannot be removed by gravity. AASHTO's *Highway Drainage Guidelines* also describe drainage structures for subsurface water. Subsurface water may destabilize road embankments and shoulders. Also, water in the pavement subgrades and structural material layers supporting traffic, though in earlier years thought to be taken into account by using saturated test samples, is now recognized as having harmful effects that should be removed by subsurface drainage systems (AASHTO, 2007). The thrust of this TxDOT research (0-6671) is the hydrologic and hydraulic impacts of TxDOT projects *on the surrounding environment*, and not the negative hydraulic or hydrologic impact *on the projects themselves*, such as the negative impact of accumulated water in the structural layer on the long-term integrity of the pavement. However, drainage technologies primarily aimed at preserving the long-term integrity of the roadway and embankments are mentioned in this research insofar as this drainage commonly exits the ROW and enters the surrounding environment.

For protecting embankments, interceptor drains remove water that has seeped into the soil, and relief drains (also referred to as horizontal drains, or longitudinal underdrain piping) prevent the rising of the groundwater table or a perched water table. Relief drains, incidentally, may also be used to drain detention and retention facilities (AASHTO, 2007).

For protecting pavement structural layers, relief drains that protect the embankments also prevent groundwater from reaching the roadbed. Edge drains along the edge of pavement allow for the rapid removal of stormwater that has infiltrated through the pavement or other surface water inflow (AASHTO, 2007).

Permeable pavement, though not always appropriate for roadways, provides a means for substantially reducing stormwater runoff. Pervious asphalt may be useful for TxDOT parking lots at highway rest areas and other TxDOT paved areas. It has been used for two parking lots in Puget Sound, Washington, where it was found to be less expensive (for the particular site) than providing the traditional pavement with an underground vault for stormwater storage (Broadsword and Rhinehart, 2010). In Auckland, New Zealand, a 200 m^2 permeable pavement test site on a roadway yielded discharge from its underdrain that was similar in peak flow and volume to the discharge yielded in predevelopment conditions (Fassman and Blackbourn, 2010). Guidelines and design software are available for roadways of permeable interlocking concrete pavements (PICP), which rely on an open-graded crushed stone base for storage, infiltration, and vehicular support (Smith and Hunt, 2010).

The primary drainage structures for preventing the elevated roadway from impounding or adversely diverting water include bridges, culverts, and roadside channels. The sizing and design of these structures is based on results yielded by the models and software discussed previously in this literature review. Also, in regard to bridges, the recently released Evaluation of Bridge Scour Research: Geomorphic Processes and Predictions (NCHRP, 2011) develops recommendations for use of specific research results by the engineering community. This study follows Hydraulic Engineering Circular No. 23 (FHWA, 2009), which provides experienced based guidance for design of countermeasures for bridge scour and stream instability. In regard to culverts, Hydraulic Engineering Circulars No. 5, No. 10, and No. 13 are combined as Hydraulic Design Series No. 5 (HDS-5), Hydraulic Design of Highway Culverts (FHWA, 2005). TxDOT research project RTI 0-6549: Hydraulic Performance of Staggered Barrel Culverts for Stream Crossings is a study of design parameters for conveying not only water but bedload as well, and includes an extensive literature review concerning these dual objectives in culvert design (Cleveland and Strom, 2010). In regard to roadside channels, Introduction to Highway Hydraulics (FHWA, 2001) provides guidance for the design of rigid (concrete lined) channel design; Hydraulic Engineering Circular No. 15 (FHWA, 2005) provides guidance for channels with flexible lining; and Hydraulic Engineering Circular No. 14 (FHWA, 2006) provides guidance for the inclusion of energy dissipaters and grade-control structures.

2.4.3 Final Design: Selection of Best System of Components

The engineer has a diversity of options for minimizing the adverse hydrologic and hydraulic impacts of TxDOT projects. NCHRP (2006) outlines a systematic approach for listing and considering physical properties of the watershed, regulatory issues, and political, economic, and jurisdictional issues so that only the most appropriate alternatives remain for consideration. Also, a quantitative tool, such as that of an analytical hierarchical process, provides a ranking and narrowing down of alternatives (Young et al., 2009). Models for optimization of placement of components and minimizing life cycle costs (as discussed in previous sections) are applied to each alternative that cannot be eliminated by rougher estimations. Finally, a design is to be achieved which meets the design criteria at the lowest life cycle cost, and with either no adverse impact for the check flood, or else an adverse impact which, due to relative insignificance in light of resource limitations, is acceptable.

2.5 CONCLUSION

This literature review has considered design criteria from a legal and ethical perspective, data collection, methods for estimating hydrologic and hydraulic quantities, and drainage system design. These various aspects are to be considered in the development of surveys and interviews.

All questions in the survey for TxDOT districts (Appendix D) and state DOTs (Appendix E) spring from this literature review or directly from experienced TxDOT personnel, with whose insights this literature review is consistent.

3. METHODOLOGY: SURVEYS AND INTERVIEWS

The literature review considered design criteria from a legal and ethical perspective, data collection, methods for estimating hydrologic and hydraulic quantities, and drainage system design. Each of these was to be considered in the development of surveys and interviews.

In regard to design criteria, the literature review suggests a trend toward increasing strictness in what are identified as adverse impacts, particularly as the "No Adverse Impact" approach is emerging. Also, over the decades, Texas has waived sovereign immunity in regard to inverse condemnation. Mitigating adverse hydrologic and hydraulic impacts of TxDOT projects are of concern to TxDOT not only because of its appreciation of communal values, but from a legal perspective as well. Surveying other state DOTs thus sought to uncover helpful design criteria that extends beyond minimum federal requirements. Surveys of TxDOT hydraulic engineering and other personnel aimed at assessing the degree to which resources are available for coordination with the local community and for effective implementation of design criteria.

In regard to data collection and methods for estimating hydrologic and hydraulic quantities, a variety of models and software are available. Relevant comparisons that would establish universal superiority of one model or software package over another are not available. The unavailability of continuous stream flow records for most TxDOT projects makes model selection, calibration, and validation difficult to establish, yet estimation of hydrologic and hydraulic quantities is essential to the design of drainage systems. More sophisticated models, while not free from error, may reduce inaccuracies by fully utilizing the resolution available in input data, but require greater expertise and time for development. Surveys and interviews thus investigated what models and software are used in TxDOT districts, any data collection or technical barriers that must be overcome in using sophisticated and more accurate models, and how hydraulic engineers verify that model results are reasonable.

In regard to drainage system design (for a given design criteria and hydrologic and hydraulic quantity estimates), surveys and interviews sought to identify the common types of structures used in the districts. Also, innovative or particularly effective design strategies were noted, so that they may be shared with other districts through this report. Furthermore, although cost analysis is beyond the scope of this study, such an inventory may prove helpful toward investigating cost reduction possibilities for TxDOT.

The surveys and interviews are also to gather information regarding any other effective practices or important challenges faced by engineers.

In addition to the literature review, input from experienced TxDOT personnel was also used to develop the surveys. Also, a basic understanding of TxDOT's structure, as discussed below, was essential for developing the surveys and on-site interviews.

3.1 THE STRUCTURE OF TXDOT

TxDOT is divided into 25 districts, each of which on average serves an area of approximately 11,000 square miles, 10 counties, and 1 million persons. The Divisions in Austin, the state capitol, provide guidance regarding design, construction, and maintenance. Project plans and specifications are generated at the district level, but reviewed by the corresponding Divisions (Bridge, Design, Environmental, Traffic, etc.), which, after final approval, coordinates the letting of the project for construction.

A movement toward each district having a District Hydraulic Engineer (DHE) began with a memo addressed to all Divisions and Districts on January 21, 2005 (Appendix C), in which the need for having a DHE to address drainage-related issues was justified, and roles and responsibilities of the DHE were identified. As of today, all districts formally have a DHE, but in many districts the DHE is an "interim" DHE, or wears several hats, such that a relatively small portion of time is dedicated to drainage issues.

Approximately three years ago, districts began to centralize such that design would occur only at each District Office. This is in fact what occurs today, except that in some cases engineers with veteran expertise had already settled far from the District Office, and have been allowed to continue practicing as design engineers at their locations.

Each district includes several Area Offices geographically spread throughout the district and that schedule maintenance and oversee the construction phase of projects in their respective areas.

The districts are grouped into four regions—North, South, East, and West— to provide administrative and project management support to the districts. Through the regional offices, human resources are shared. In September 2009, districts began assisting one another with engineering. Though this sharing is not yet prominent, it is sometimes inter-regional, and may be becoming more common as budget constraints intensify the need to fully utilize expertise and time through formal "work share" agreements.

3.2 SURVEY AND INTERVIEWS FOR TXDOT DISTRICTS

An effective means for understanding hydrology- and hydraulic-related issues in each district is through the DHE. A link to a survey was delivered by e-mail to the DHE or Interim DHE of each District through utilization of SurveyMonkey™ software. To encourage forthrightness, anonymity was assured by not requiring any information that would uniquely identify any district or person completing the survey. Appendix D displays the survey and summary results (which will be discussed in Section IV) for the 23 of 25 districts who responded. The DHEs were also interviewed to gain a deeper and broader understanding than would be acquired through the survey. For 17 of the 25 districts, the interview was conducted at the District Office, while for the remaining eight districts (Austin, Atlanta, Brownwood, Lubbock, Odessa, Paris, Tyler, and Wichita Falls) the interview was conducted over the telephone and/or through one or more e-mails due to remoteness, difficulty in scheduling, or other reasons.

Appendix F lists the topics covered in the DHE interviews. The degree with which each topic was covered varied from district to district, based on relevance. For some of the districts, additional personnel joined the DHE during the interview to supplement the DHE's understanding and experience. In two of the districts, one with a large, extremely challenging urban center, maintenance personnel were interviewed by themselves, with questions appearing in Appendix G.

Also, in four of the districts with a District Office in the largest urban centers and in the six districts having a District Office in the smallest urban centers, the local Floodplain Administrator (FPA) serving that urban center or an area near it was interviewed. This interview helped assess the working relationship between the FPAs and TxDOT. These questions appear in Appendix H.

3.3 STATE DOT SURVEY

Researchers surveyed state DOTs to better develop a more comprehensive listing of best practices and adverse impact descriptions. Each state DOT typically has a State Hydraulic Engineer or person with a similar title who is responsible for all DOT drainage-related issues. A link to a survey was delivered by e-mail to each such person through utilization of SurveyMonkey™ software. To encourage forthrightness, anonymity was offered by not requiring any information that would uniquely identify any state or person completing the survey. Appendix D displays the survey and summary results (which will be discussed in Section 5) for the 35 of 49 states who responded.

4. RESULTS AND DISCUSSION OF SURVEYS AND INTERVIEWS WITH TXDOT PERSONNEL AND TEXAS LOCAL FLOODPLAIN ADMINISTRATORS

4.1 GENERAL PATTERNS

Interviews indicate that TxDOT districts have generally reduced their reliance on consultants, at least in part to reduce costs. Due to the One TxDOT effort initiated two years ago, there is a trend toward overly busy districts being aided in design by less busy districts. Also, one of the DHEs interviewed had shared his modeling expertise on projects of two other districts. A former DHE expressed that resistance may be encountered from the upper management in some districts to share their human resources with other districts.

In some areas, especially less populated areas, there is a tendency for runoff from development to be unchecked by the county, drainage district, or other relevant agencies. In such areas, TxDOT will likely proceed with little dialogue with such agencies, even when TxDOT attempts to initiate that dialogue. However, as development occurs, hydrologic and hydraulic impacts escalate, stressing TxDOT infrastructure and other infrastructure, to the detriment of the public welfare. Some TxDOT districts therefore encourage these local agencies to impose stormwater runoff standards on development and to begin developing appropriate infrastructure. Such districts also document these interactions.

A disproportionate number of drainage-related complaints and lawsuits are due to events occurring during the construction phase of projects. The transition from the existing structures to the proposed structures is often a period of reduced hydraulic capacity.

Accessible and thorough documentation may be thought of as a glue that helps hold together TxDOT's various departments, as well as TxDOT's past, present, and future. TxDOT appears to be in a transition toward a more sophisticated and accessible system of documentation.

As discussed in the 2005 Memorandum addressed to TxDOT District Engineers (Appendix C) the DHE is intended to be the central player through whom hydrologic and hydraulic impacts are addressed. A key question is whether the DHE is dedicated to drainage-related issues full-time or only part-time, and how much of a difference that might make. This will be the first aspect of the study examined in detail, and then other aspects will be examined in detail.

4.2 TXDOT DISTRICT SURVEY

4.2.1 The Relation of DHE Status to Rigor in Addressing Drainage Issues

One of the key issues in relation to how rigorously districts address drainage issues in the design phase is whether the District Hydraulic Engineer is dedicated solely to hydrology and hydraulic issues ("full-time DHE") or plays other roles as well ("part-time DHE"). Responses to survey questions that most closely reflect the degree of rigor with which drainage issues are addressed are reviewed and compared in this subsection. The responses to other questions are summarized in the subsequent subsections.

Districts generally do not have a full-time DHE. On average, based on responses to Question #3 of the TxDOT District Survey in Appendix B, "What percentage of the time does the DHE (or Interim DHE) perform drainage duties?" DHEs act as DHEs only 30 percent of the time. Only three districts have DHEs who responded "100 percent" to this question. If we exclude these three, DHEs in the remaining districts are dedicated to drainage duties on average only 16 percent of the time.

Based on interviews, all three full-time DHEs are located in districts having a large city. Part-time DHEs are in districts that are less densely populated, though some do have cities of significant size. One might pose the question, "Do districts without a large city really need a full-time DHE, or does a part-time DHE suffice?" To help answer this question, survey results were divided into full-time DHE responses and part-time DHE responses, as indicated in Table 4.1 and Table 4.2. In general, responses that indicate that the activity in question is performed earlier or more frequently are preferred. For example, the response "Always" is preferred to "Sometimes" to Question #1 (regarding *how frequently* the DHE evaluates projects for negative hydrologic and hydraulic impacts), and "Planning and Schematic" is preferred to "Late in PS&E" as a response to Question #2 (regarding *when* the DHE evaluates the project for negative HH impacts). In Table 4.2, the "x" indicates which DHE category (full-time or part-time) provided the responses indicating that the activity is on average performed more frequently or earlier, based on weighted averages of the percentages shown in Table 4.1.

For question #1 shown in Table 4.1, the possible answers to the question, "Does the DHE evaluate district projects for negative hydrologic and hydraulic impacts?" are "Always," "Most times," "Sometimes," and "Rarely" (as shown in Appendix D). All three full-time DHEs answered "Always" to this question, while responses among part-time DHEs were split between "Most times" and "Sometimes." Is it possible that districts without a large urban center do not always need the DHE to evaluate projects for negative hydrologic and hydraulic impacts? It is the authors' opinion that the DHE should evaluate each project, though in some cases the evaluation process may be rather quick in rural areas. This indeed is the practice of the full-time DHE's for rural areas. Although the full-time DHEs are all in districts containing a large city, each such district spans multiple counties with substantial rural areas within which each TxDOT project is always evaluated for hydrologic and hydraulic impacts. One must not underestimate the severity or subtlety with which such impacts may strike in such areas. For example, as is discussed in Section 4.4.1, in one district additional layers of asphalt in overlay projects at a low water crossing in a rural area ultimately led to flooding of a farmer's land and ranch home. TxDOT had to buy the property. In another district, a farmer complained when a TxDOT project, which was seemingly quite simple from a drainage perspective, led to backwater effects when the farmer altered the direction of his furrows and the drainage pattern. The TxDOT project hindered the farmer from exercising an effective farming practice on his land. The DHE needs to be involved in all projects, and left to decide the extent of time and effort required for evaluation of hydrologic and hydraulic impacts. Table 4.1 suggests that perhaps part-time DHEs do not assert and are not expected to assert full ownership of drainage-related issues because of their other responsibilities, and many projects may be constructed without their participation.

The histogram of responses for Questions #1, #2, #6, #8, #9, #10, and #11 in Table 4.1 show that, in general, full-time DHEs are more active in projects and begin to participate in projects earlier than part-time DHEs. Table 4.2 summarizes the histograms of Table 4.1 and, for all questions except #2 and #8, is based on weighted averages to indicate whether the full-time DHE or the part-time DHE is involved earlier or more frequently. The weighted averaging requires a quantitative value to be assigned to each category. Categories were given values of 1, 2, 3, etc. corresponding to their position from left to right on the histogram. For example, for #1, a value of 1 was assigned to "Always," 2 to "Most times," and so on. The weights are then the percentages or number of full-time or part-time DHEs having their response in that category. For #2 and #8, which instruct the respondent to "Check all that apply," and it is desirable that all categories be checked, the average percentage was simply calculated. The results are illustrated in Table 4.2. Although the numbers of full-time DHEs are few, allowing for some differences in individual questions to be attributed to chance when considered in isolation, the consistent pattern shown among the multiple questions provides a convincing illustration of the advantages to having a full-time DHE over a part-time DHE. Full-time DHEs evaluate projects for hydrologic and hydraulic impacts more consistently (#1), become involved in projects earlier (#2), are involved in the Planning and Schematic Phase of projects more frequently (#6), consider FEMA floodplains earlier (#8), coordinate with the local FPA more frequently for projects that do not occur within a FEMA-zoned floodplain (#9), coordinate with the local FPA more frequently for projects that do occur in a FEMA-zoned floodplain (#10), perform hydraulic analysis more frequently for pavement overlays (#11.A), perform hydraulic analysis more frequently for culvert lengthenings of more than 10 percent (#11.C), and perform hydraulic analysis more frequently for installations of metal or concrete guard rails at culverts (#11D). Interestingly, the only drainage activity in which the part-time DHE engages in more frequently than does the full-time DHE is that of performing hydraulic analysis for a culvert lengthening of less than 10 percent (#11.B). However, adequately informed DHEs are aware that TxDOT, through its own in-house study, has ascertained that a 10 percent or less lengthening of a culvert does not significantly increase water surface elevations. Here we may have an example of how the limited time that part-time DHEs have in addressing drainage-related issues may cause them to be less informed and to use what little time they do have less efficiently.

Table 4.1. Distribution of District Survey Responses for Full-Time DHEs (Dark Gray) and Part-Time DHEs (Light Gray).

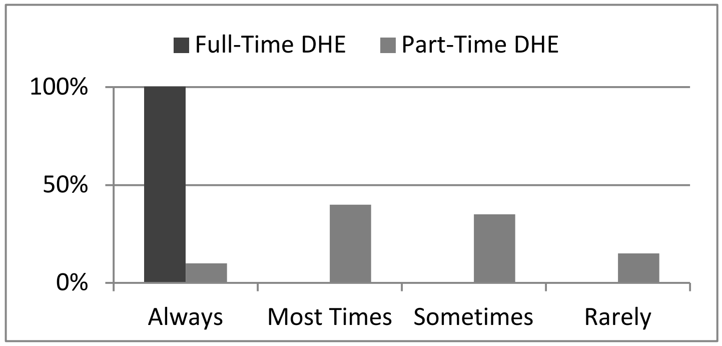
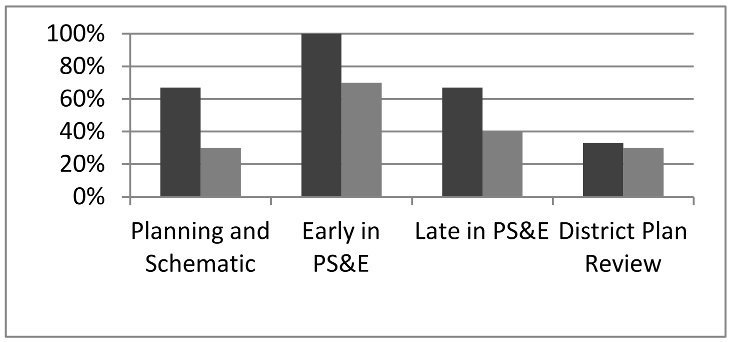
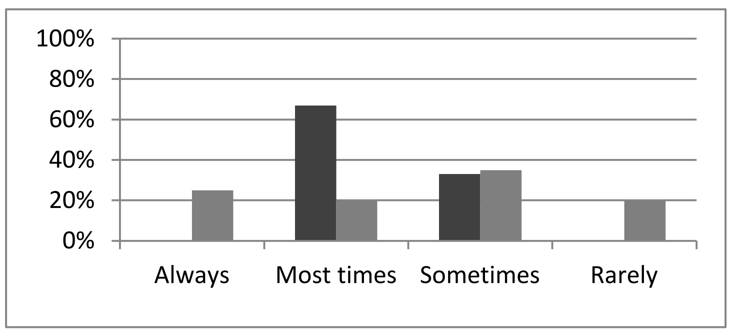
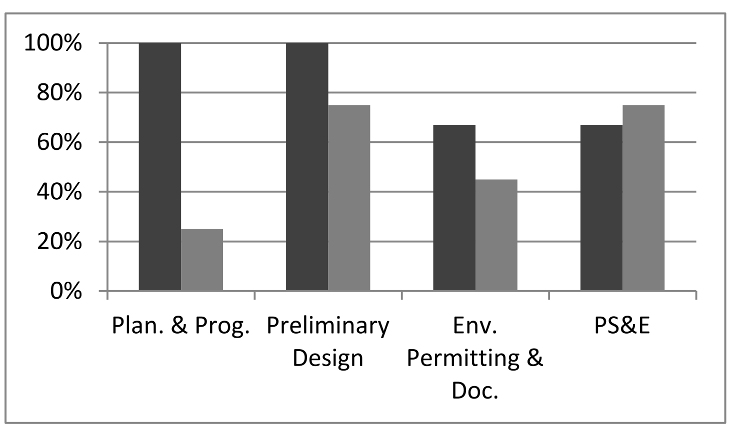
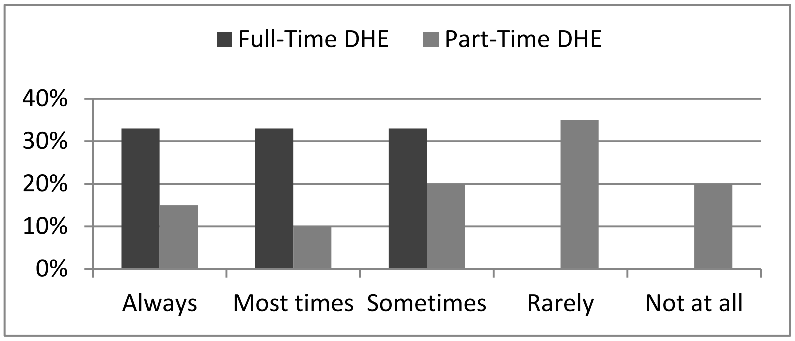
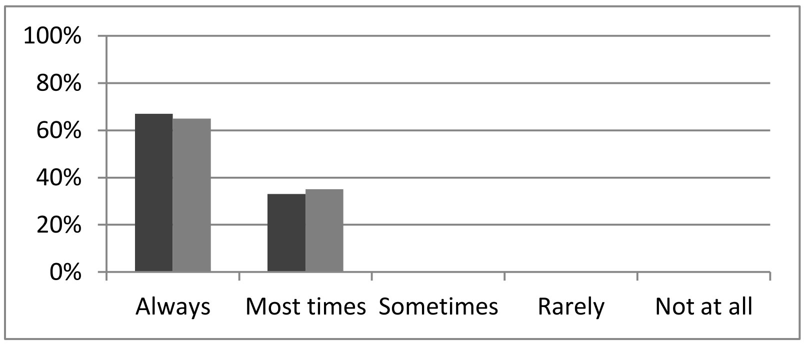
1. Does the District Hydraulic Engineer (DHE) or the interim DHE evaluate district projects for negative hydrologic and hydraulic impacts?	
2. At what stage of plan development does the DHE or interim DHE evaluate district projects for negative hydrologic and hydraulic impacts? Check all that apply.	
6. How frequently is the DHE or a hydraulic staff member involved in the Planning and Schematic Phase of new projects?	
8. At what point in the design process are the FEMA National Flood Insurance Program [NFIP] floodplains considered? Check all that apply.	

Table 4.1. Distribution of District Survey Responses for Full-Time DHEs (Dark Gray) and Part-Time DHEs (Light Gray) (Continued).

9. For projects that do NOT occur within a FEMA-zoned floodplain, does coordination take place with the local Floodplain Administrator?

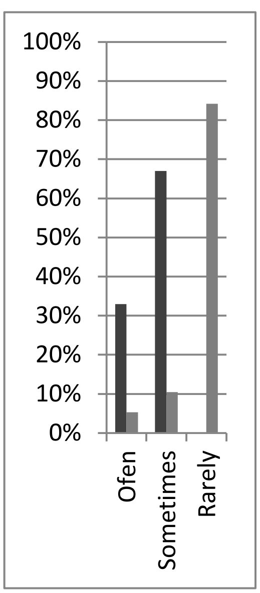


10. For projects that DO occur in a FEMA-zoned floodplain, does coordination take place with the local Floodplain Administrator?

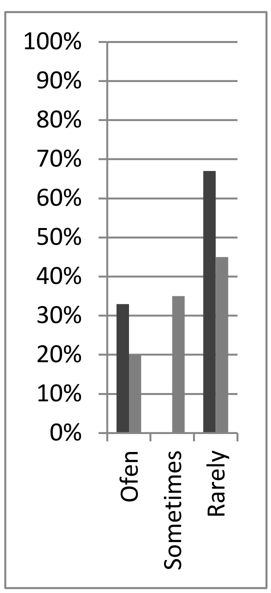


11. For recent projects, which of the following types involved hydraulic analysis?

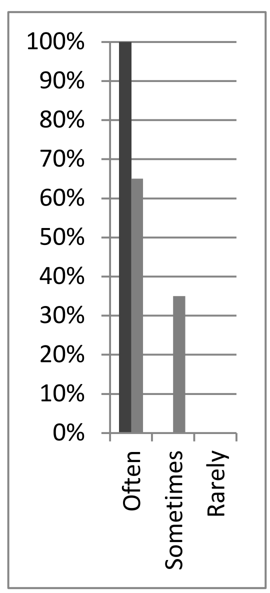
A. Pavement overlay



B. Culvert lengthening, < 10% original length



C. Culvert lengthening, > 10% original length



D. Installation of metal or conc. guard rail at culvert

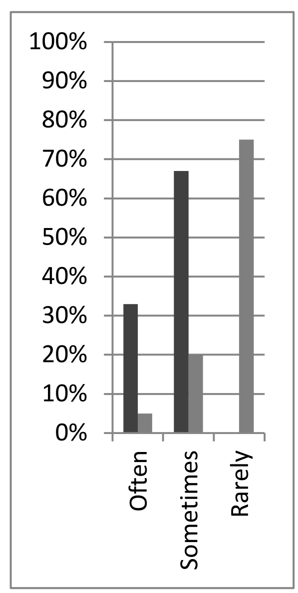


Table 4.2. Extent and Earliness of District Hydraulic Engineer (DHE) Involvement in Design Process, for Full-Time DHEs and Part-Time DHEs.

SURVEY QUESTION	"x" to indicate which DHE performs the activity earlier or more frequently	
	Full-time DHE	Part-time DHE
1. Does the DHE evaluate district projects for negative hydrologic and hydraulic impacts?	x	
2. At what stage of plan development does the DHE evaluate district projects for negative hydrologic and hydraulic impacts?	x	
6. How frequently is the DHE or a hydraulic staff member involved in the Planning and Schematic Phase of new projects?	x	
8. At what point in the design process are the FEMA National Flood Insurance Program (NFIP) floodplains [first] considered?	x	
9. For projects that DO NOT occur within a FEMA-zoned floodplain, does coordination take place with the local Floodplain Administrator?	x	
10. For projects that DO occur in a FEMA-zoned floodplain, does coordination take place with the local floodplain administrator?	x	
11. For recent projects, which of the following types involved hydraulic analysis?		
A. Pavement overlay	x	
B. Culvert lengthening, less than 10% original length		x
C. Culvert lengthening, greater than 10% original length	x	
D. Installation of metal or concrete guard rail at a culvert	x	

Further examination of the responses to Question #8 indicates that all full-time DHE's responded with the earliest point possible, the "Planning and Programming" phase, and achieve the ideal. Meanwhile, part-time DHEs, on average, first consider the FEMA floodplains during the "Preliminary Design" phase, or slightly later.

Questions #9 and #10 concern coordination with the local Floodplain Administrator (FPA).

The average responses for question #9 indicate that for districts with a full-time DHE coordination with FPA occurs much more frequently than it does for part-time DHEs when the project is not within a FEMA-zoned floodplain. However, interviews with several of the districts having part-time DHEs suggest that for many such projects there would be no FPA with whom to coordinate. Question #10 indicates that, for projects within the FEMA-zoned floodplain, districts with a part-time DHE are nearly as consistent as are districts with a full-time DHE in coordinating with the FPA. This suggests that the TxDOT culture is generally appreciative of coordinating with local authorities, though some DHEs coordinate with the FPA "Most of the time" rather than "Always."

Table 4.3 summarizes responses to Questions #12 and #13 of the TxDOT districts survey in Appendix B for the full-time DHEs and the part-time DHEs. For question #12, the DHE is asked to indicate the number of complaints received over the past 5 years in each of several categories. The exact number is not expected to be recalled. The DHE is asked to merely indicate that range in which the number of complaints likely falls: 0, 1–5, 6–10, 11–20, and greater than 20. In order to facilitate calculation of an average, the midpoint for each range selected was used as representative of the answer. None of the respondents selected "greater than 20" for any of the complaint categories. For Question #13, the percent of respondents who indicated that litigation or mediation had occurred within the past 5 years was calculated.

Districts with full-time DHEs are shown to receive more complaints than do those with part-time DHEs. Surveys and interviews reveal a tendency for complaints to be heard and addressed by the Area Offices, and not always being reported to the DHE. Most likely, the number of complaints occurring over the past 5 years is much greater than that suggested by Table 4.3. However, the proportionality displayed in Table 4.3 may be fairly representative of the proportionality of actual complaints. It seems likely, for example, from discussions with various TxDOT personnel other than DHEs that "Backwater from a TxDOT bridge or culvert" and "Increased flooding due to increased runoff caused by the TxDOT project" are the most common complaints. Districts with full-time DHEs also each contain a large city in geographic areas prone to severe flooding.

Question #12 of Appendix B also invites the respondent to identify complaints that are "other" than of the four categories listed for the question. Four respondents provided answers under this category. One indicated a complaint that TxDOT had increased the drainage capacity of a structure, and that downstream flooding was occurring as a result. Another respondent indicated that complaints are often that a TxDOT culvert capacity is inadequate. Two other DHEs expressed that the Area Offices would likely be more aware of complaints.

This last observation, that the DHE might not be aware of complaints, makes it clear that the effectiveness of the district in preventing adverse hydrologic and hydraulic impacts may not be measurable by the number of complaints heard by the DHE. Furthermore, even complaints that are heard are not always valid. Complaints that rise to the level of litigation or mediation are more likely to be heard by the DHE and are also more likely to be valid. The survey results show that none of the districts with full-time DHEs have been involved with drainage-related litigation or mediation within the past 5 years, while 21 percent of districts with part-time DHEs have. This difference is perhaps more noteworthy when one considers that the districts with full-time DHEs all contain particularly challenging large cities that are prone to flooding due to geographic location. The greater involvement of full-time DHEs appears to lead to less litigation and mediation.

Table 4.3. Complaints and Litigation or Mediation for Full-Time DHE Districts and Part-Time DHE Districts.

SURVEY QUESTION	FULL-TIME DHE	PART-TIME DHE
12. …In the past 5 years, how many of each of the following complaints has this district heard?		
Diversion of a stream or drainageway from its natural or existing path	1.0	0.7
Backwater from a TxDOT bridge or culvert	6.3	1.7
Increased flooding of property due to TxDOT embankment running parallel to a stream and encroaching upon the stream's floodplain	2.0	1.1
Increased flooding due to increased runoff caused by the TxDOT project	10.3	1.6
13. …Within the past 5 years, has the district been involved with hydraulic- or hydrology-related litigation or mediation?	0%	21%

The question posited near the beginning of this subsection, "Do districts without a large city really need a full-time DHE, or does a part-time DHE suffice?" may now be considered in light of the above evidence: While full-time DHEs consistently or very nearly consistently fulfill drainage duties that are necessary even for rural projects, part-time DHEs apparently are distracted with other duties or are otherwise unable to fulfill those duties consistently and efficiently. If TxDOT desires to thoroughly address drainage issues within its present structure, full-time DHEs are apparently needed. The issue of full-time versus part-time DHEs is to be revisited in Chapter 6 Recommendations.

4.2.2 Whether DHE Is Certified Floodplain Manager; Position of DHE

As shown by the responses to Question #4 in Appendix B, approximately a third (34.8 percent) of the DHEs are Certified Floodplain Managers (CFM), and the rest are not. All three full-time DHEs are CFMs. Only 20 percent of part-time DHEs are CFMs.

Question #5 asks to whom the DHE reports. All but one DHE reports to an intermediate manager rather than to the District Engineer, suggesting a relatively low status of the DHE in each district. Only one DHE, a part-time DHE, reports directly to the District Engineer. As part-time DHEs play multiple roles, it is not known whether this DHE reports to the District Engineer *as a DHE* or in some other capacity, such as a District Design Engineer.

Question #7 asks if stormwater quality is part of the DHE's duties. Only three—two part-time DHEs and one full-time DHE—responded "yes" to this question.

4.2.3 Helpful References or Resources

Question #14 Open Responses of Appendix B lists various references and resources the DHEs find helpful in estimating and/or avoiding negative hydrologic and hydraulic impacts. Eleven of the DHEs identify the TxDOT HDM as their most or one of their most important references or resources. Other references identified include FHWA publications, Managing Floodplain Development Manual, and TxDOT Research Project References.

Several DHEs did not identify a text as their most important reference or resource but data or field information, such as USGS maps or that obtained from site visits or visits with maintenance personnel.

Two respondents identified software as an important resource, particularly HEC-RAS, HEC-HMS, ArcMAP, and Culvert Analysis.

Two DHEs identified training and understanding gained from working with experienced engineers as an important resource.

4.2.4 Most Challenging Drainage Issues

Question #15 of Appendix B asks what drainage issues are the most challenging, and for which the District would most likely see additional assistance. The most frequent choice (14 of the 23 respondents) was "Selection and/or use of software." The second most frequent choice (13 of 23) is closely related to the first: "Assessing, predicting, or mitigating hydrologic/hydraulic impacts during the design phase." Also, two of the responses under "other" are modeling and design issues – the acquisition of licenses for storm sewer modeling software, and the "lack of experience of many designers, especially in the FEMA floodplain."

The remaining choices from the list, "Acquiring easements for drainage," "Maintenance of drainage," "Diversion of drainage," and "Temporary drainage/flooding/complaints during construction" each were selected by approximately one-fifth of the DHEs.

Two of the DHEs stated under "other" that design of detention ponds or detention facilities are among the most challenging. Another DHE is challenged by storm surges in tidal areas. Finally, one DHE is challenged by developers who change drainage patterns in a manner that is contrary to that for which the TxDOT infrastructure was designed.

4.2.5 Noteworthy Solutions

Question #16 inquires regarding noteworthy solutions. Most DHEs (20 of 23) indicated that they knew of no noteworthy solutions.

The “Durazno Ponds Girl Scout Channel” is actually two projects, “Durazno Ponds” and the “Girl Scout Channel,” listed in a single line by the surveyee. What is noteworthy about both these projects is the degree of coordination between TxDOT and the city. In regard to the Durazno Ponds project, TxDOT assisted a city in mediating a severe flooding problem, which was the city’s responsibility. TxDOT assisted by optimizing the storage capacity of Durazno Ponds. In regard to the Girl Scout Channel project, during heavy rains large runoff volumes would race down a city street at flowrates too great to allow for thorough interception by the Girl Scout Channel, which was intended to carry the flow to a nearby dam. A downstream neighborhood and a TxDOT frontage road had been flooded as a result. TxDOT proposed the Girl Scout Interceptor to better accommodate these runoff volumes.

One DHE describes a simple way to avoid adverse impacts—maintain the existing roadway profile for mill and overlay projects in FEMA floodplains. That same DHE has found in-line detention to be an effective solution to increased runoff from the state ROW. The interview with this DHE suggests that the DHE utilizes in-line detention as part of a decentralized or Low-Impact Development approach.

4.2.6 Comments

Questions #17 and #18 ask for comments or advice for other TxDOT districts or for the TxDOT Design Division, or any other comments. A total of eight DHEs provided a comment or advice. (The Survey Monkey indicates that all the DHEs answered at least one of these two questions, but most of these answers were such as “no” to indicate that they had no comment.)

Four of the comments suggest additional training or guidance is needed, and two of these four explicitly state this training is needed in relation to modeling hydrologic or hydraulic quantities. An updated version of the TxDOT Hydraulic Design Manual is requested. A document or presentation relating Texas Water Law to hydraulic analysis is also requested. As is stated in Section 4.4, in-person interviews with DHEs indicated that part-time DHEs may have too little time to put into practice what they learn in the training workshops, so that what they learn is not reinforced and may be lost. Two of the comments concern the position of the DHE. One of these requests that the Design Division emphasize the importance of having a DHE in every district. Another notes that, in their experience, having the DHE directly under the District Design Engineer allows for earlier and more thorough involvement in drainage issues.

One DHE asks if there has been a resolution regarding the type and format of information to be included in Plans, Specifications, and Estimation (PS&E) packages. Finally, one DHE simply expresses appreciation for the questions and the interest shown.

4.3 SURVEY OF LOCAL FLOODPLAIN ADMINISTRATORS

Researchers contacted 11 local Floodplain Administrators. Five of these 11 were from districts with highly populated urban centers, and the other six were from the least populated urban centers. Appendix A shows the questions asked. The survey was answered by e-mail or through telephone conversation.

TxDOT HDM (2011) calls for coordination with the local FPA and submission of final plans and hydraulic calculations to the FPA.

Five of the six FPAs serving in sparsely populated areas indicated that they are satisfied with their working relationship with TxDOT. The one who is not satisfied reported not having been contacted by or having received any documents from TxDOT since beginning to work as the FPA 10 years ago. This FPA noted that perhaps TxDOT is working through city officials, but had nonetheless never received anything. The FPA added that better communication with the FPA could have helped TxDOT become aware of the need for underground drainage for a project that TxDOT constructed more than 10 years ago, for which TxDOT is now in mediation. A second FPA, though generally satisfied with the working relationship, received final plans only "sometimes."

Researchers interviewed five FPAs serving in districts with large urban areas. Two of them indicate that they are satisfied with the working relationship, two of them indicate dissatisfaction, and one is only "somewhat satisfied."

The two dissatisfied FPAs are actually serving in the same district, one in a large urban center, and the other in a less populated neighboring county into which the urban center is expanding. These FPAs state that the point at which they are contacted regarding TxDOT "varies a lot" or "varies, and is usually after the design is more than halfway done." One of them indicates usually not receiving a set of plans, and says, "I ask for reports, and don't get a response." The other indicates receiving plans with a "disconcerting inconsistency."

One of the satisfied urban FPAs also noted being contacted inconsistently by TxDOT, and stated that the inconsistency seemed to be due to TxDOT sometimes bringing in outside help to design projects. This outside help is likely consultants rather than TxDOT from other districts, as the practice of districts helping each other began only in 2010, and is not widespread. This FPA would like to be contacted very early, even with a quick phone call, and then inform TxDOT of the documents s/he would like to have. This FPA notes that TxDOT "has gotten much better…They used to be really bad…in the 80s through late 90s it had an attitude that it's a superior agency that didn't have to comply with local ordinances."

Actually, under state case law, state agencies, such as TxDOT, are prohibited from applying for permits from subordinate jurisdictions (TxDOT HDM, 2011). So TxDOT really does not have to comply with local ordinances. Nonetheless, the desire or expectation of compliance with local ordinances is a source of dissatisfaction for one of the dissatisfied FPAs and the "somewhat satisfied" FPA. This latter FPA provided examples of local ordinances that it desired TxDOT to follow: 1) No increase in floodplain depth; and 2) Assume fully developed future conditions for hydraulic design.

The "somewhat satisfied" FPA serving in the urban area since 1992 states that 10 years ago TxDOT did not reach out to communities with information. Since then, it makes more of an effort to inform and enlist comments. Usually TxDOT calls and comes to the FPA's office to discuss projects.

As seen in the above discussion, two FPAs discussed an improved working relationship with TxDOT. A key reason for the improved relationship may be that in 2004 through 2008 TxDOT sponsored FEMA-led training in most of TxDOT's 25 districts. TxDOT personnel also assisted in the training. Training suddenly became much more accessible to FPA and TxDOT personnel; until then FEMA had provided training twice per year at only two locations in the vast state. Also, since TxDOT design engineers were invited to attend, it allowed FPAs and engineers to interact and better understand the challenges faced by each other. Because this training was a key reason for improved FPA/TxDOT relationships, those relationships may begin to suffer if no replacement is implemented.

The hiring of consultants who conduct FPA coordination is worthy of close examination. In at least one TxDOT district, the DHE now informs TxDOT project managers that consultants hired for TxDOT projects should not be allowed to conduct FPA coordination. This is because, according to a former DHE, such allowance had shown itself to increase the project costs due to the consultant promoting the preferences of the FPA. In some cases the consultant was a "roadway" engineer who knew little about hydrology and hydraulics engineering and the relevant federal and state laws, and so may have promoted the FPA's preferences out of ignorance. In other cases, the consultant may have understood the hydrologic and hydraulic laws and issues quite well, but may have had a vested interest in promoting the FPA's preferences.

4.4 INTERVIEWS WITH TXDOT PERSONNEL

TxDOT personnel were interviewed to develop a list of descriptions of particular cases of litigation, mediation, and threatening complaints. TxDOT personnel were also interviewed to more thoroughly investigate current practices, practices needed or sought for addressing challenges, and best practices. The electronic survey introduces but does not delve into these concerns as deeply as can interviews, as a comparison of the list of electronic survey questions in Appendix D compared to the comprehensive list of interview questions in Appendix F suggests.

4.4.1 Litigation, Mediation, and Conflicts

One of the primary tasks of the interviews was to learn more about any litigation, mediation, or other conflicts. These are discussed below. Information in such matters is not always freely available due to legal concerns. Some of the details may therefore be inaccurate, but the gist of the accounts is trustworthy.

4.4.1.1 Inadequate Drainage of Farmland after Altering Direction of Crop Rows

The design of the drainage system for a TxDOT project in a rural area was based on the orientation of the crop rows at the time of the site visits, and the possibility of re-orienting the crop rows was not considered. Sometime after construction, the farmer altered the direction of the crop rows and therefore the drainage pattern into the designed roadside ditch, which was now unable to accommodate the flow, and prevented the farmer's land from draining properly.

4.4.1.2 Temporary Concrete Barrier in a Floodplain

In 2001, TxDOT began constructing additional lanes to a highway passing through a floodplain of a medium-sized city. As right-of-way was unavailable for broadening the overall width of the highway, the plans called for lanes to be added internally, and the placement of temporary concrete barriers between the opposite-bound lanes. Shortly after the barriers were placed, an event of magnitude greater than a 100-year flood and less than a 500-year flood occurred. Stormwater upstream of the barrier rose to a height of 3.0 to 3.5 ft in the lanes before the barrier ruptured, and the water rushed downstream. The flow maintained a height of 2 to 3 ft in the lanes for several hours. After approximately 5 hours the flooding cleared from the lanes.

Within a week after the event, an attorney attempted to file a class-action lawsuit on behalf of the approximately 100 upper-middle class and upper class homeowners on the downstream side of the highway, claiming that the concrete barrier, when it ruptured, led to higher water levels than would have been reached had there been no barrier.

TxDOT hired a consultant. The consultant used Next Generation Radar (NEXRAD) data from the National Weather Service and calibrated them to rain gauge data to generate the best possible representation of the magnitude and spatiotemporal distribution of the rainfall, and used HEC-HMS and HEC-GeoHMS for modeling. The consultant estimated that the water level in the area of the downstream homeowners would have reached nearly the same height—only a 0.1 ft difference—had the concrete barrier never been placed. The court's ruling favored TxDOT and required no mediation.

Estimates showed that the upstream residents were actually more adversely affected by the barrier than were the downstream residents. These upstream residents filed a claim shortly before the statute of limitations expired, but did not succeed against TxDOT.

4.4.1.3 Inadequately Sized Culvert for Rural Highway Stream Crossing

Several years ago, a culvert for a rural stream crossing was allegedly undersized for the level of development at the time of design, as suggested by the design calculations compared to FEMA-estimated elevations. TxDOT lost the case in 2008, and apparently did not appeal. TxDOT is now in the planning phase of projects to mediate the problem.

4.4.1.4 Expanding ROW Leads to Flooding of Low-Lying Property

A property owner in a low-lying area complained of flooding after completion of a TxDOT project in which the ROW was expanded. To mediate the problem, a TxDOT culvert in conflict with a city culvert needed to be adjusted for better drainage.

4.4.1.5 Overlaying at Low Water Crossing

In a rural area, a low water crossing was repeatedly overlaid over the years for maintenance. Hydrologic and hydraulic calculations were not performed as the elevation of the crossing increased in stages. Eventually, TxDOT was sued for the flooding of a nearby farm land and ranch house. TxDOT paid for the land and ranch house, and leased it to the owner for a nominal fee, with the understanding that TxDOT could not be sued again should the flooding be repeated.

4.4.1.6 Tailwater Flooding Due to Increased Culvert and Roadside Channel Capacities

A TxDOT project along an FM road as it passes through a small town provided an increased culvert capacity and a concrete-lined roadside channel downstream of the culvert. The DHE confirms that the project, designed by a consultant, causes flooding of yards at the downstream end of the channel, and that the property owners have complained.

4.4.1.7 Increasing Road Elevation Floods Church in Floodplain

A rural highway was widened in the 1980s, and the elevation of the crest after the improvement was 8 in. higher than that of the prior crest. A wooden church in the floodplain allegedly flooded as a result. An investigation is in progress.

4.4.1.8 Outfall Discharge Thought to Erode Property

A plaintiff argued that the discharge rate from an outfall at his property had increased due to a TxDOT project and was now causing more erosion. The plaintiff did not win because, according to district personnel, it was judged that erosion would have continued to occur anyway.

4.4.1.9 Construction Barriers Thought to Cause Increased Backwater

In a TxDOT project with a Metropolitan Planning Organization (MPO), the plaintiff asserted that backwater was due to construction barriers placed by TxDOT. The plaintiff was unsuccessful as it was discovered that two mattresses and other large items had clogged a 60 in. storm sewer.

4.4.1.10 City Does Not Fulfill Infrastructure Commitment

In 1962, TxDOT raised the road profile of an interstate highway project with an agreement from the city that the city would be fully responsible for any flooding that would result, and would build an appropriate drainage infrastructure to accommodate the flooding. In 2006, the city still had not constructed that infrastructure, and a large storm event caused catastrophic flooding. Initially, the city considered that TxDOT might be held responsible, as it had found no record of the 1962 agreement. When a TxDOT engineer found a note on the project plans indicating what the city had agreed to, the city quickly accepted responsibility.

4.4.1.11 TxDOT Efforts Harmed by Developers' Activity

Water that used to be going through culverts was diverted by developers so that it now flows into a stream that passes under a TxDOT bridge on an FM road near a small town. The diversion was not reported and was apparently unauthorized. Activities such as this cannot be reasonably expected to be accommodated by TxDOT drainage systems, and lead to hydrologic and hydraulic impacts that harm the public welfare and may damage TxDOT infrastructure.

4.4.1.12 Unauthorized Altering of Elevations within TxDOT ROW

One TxDOT maintenance person reported that businesses along a TxDOT roadway will sometimes extend driveways into the TxDOT ROW such that the elevation within the ROW is raised and neighbors are more likely to be flooded. This violation may occur for driveways for which TxDOT granted a permit, but which are constructed contrary to the permit while TxDOT inspection personnel are off for the weekend. Oftentimes it may be less expensive for TxDOT to physically mediate the problem at its own expense rather than pursue litigation.

4.4.2 Current, Sought, Best, and Ideal Practices

This section identifies and discusses best practices that are utilized by only one or some of the districts, and that are generally not already explicitly recommended by TxDOT HDM (2009). Those districts not practicing them will then have the opportunity to consider what may be an improvement over their current practices.

Current practices and ideal practices are also discussed briefly to place best practices in context. At times current practices in one subsection may impact the ability to engage best practices in another subsection. For example, if current practices do not carefully document high water events (4.4.2.6), then best practices regarding model validation (4.4.2.3) may be unachievable. However, the mere mentioning of a practice as a current practice is not intended to suggest that it should be changed. Indeed, many of the current practices have passed the test of time and are to be respected. Ideal practices currently require too much personnel time or other expenses for implementation. They are practices which TxDOT may be moving toward in the upcoming years, and help provide a sense of direction.

4.4.2.1 Hydrologic Modeling

Currently, districts use the Rational method for areas of less than 200 acres. For larger areas, districts rely on regional regression equations or unit hydrograph methods such as Natural Resources Conservation Service (NRCS) curve number.

The Rational method, which was originally developed by Kuichling (1889), estimates the peak discharge, Q_p, as a function of the rainfall intensity i, the area A, and the empirical runoff coefficient c of a drainage area: $Q_p = ciA$. The TxDOT HDM states that this method is appropriate for watersheds less than 200 acres in size and in which natural and man-made storage is minor. Interviews reveal that the districts consistently use the Rational method for such small areas.

NRCS curve number methods include TR-55 (NRCS, 1986) (intended for drainage areas having a time of concentration that does not exceed 10 hours) to calculate peak discharge, TR-20 (NRCS, 1992) for providing more precision to accommodate larger drainage areas, and the unit hydrograph approach to estimate the entire runoff hydrograph rather than only the peak discharge. The methods all have in common the use of curve numbers that are empirically established and published in the literature for combinations of soil groups and land use. The curve number value may be adjusted based on antecedent moisture conditions and slope.

Most districts employ at least one NRCS method. Recently, adjustment values have been generated to adapt the NRCS curve numbers to the state of Texas, as will be presented in TxDOT HDM (2011), but are already being used by at least one district. The DHE for that district claims to be getting more realistic results with the adjusted curve number values.

Regional regression equations have been developed for 11 regions in Texas and are presented with coefficient values in the TxDOT HDM (2009). The coefficients to be used in the equations are presented in a table as a function of region and zone. Other factors that go into the equation include the drainage area, the mean channel slope, and a basin-shape factor. These regional regression equations are intended only for rural, uncontrolled watersheds.

The regional regression equations enjoy widespread usage among the districts because of their ease of use. One DHE expressed frustration that the confidence band for the regression equations, at least when applied to projects in their area, are too broad, and that, for example, aiming for the 95 percent upper limit will yield designs that are ridiculously large. Another DHE observed that the regression equations are most helpful when the "blue line" on USGS topographic map runs across nearly the entire drainage area/watershed being modeled. A new set of regional regression equations, the OmegaEM regression equations (Asquith and Roussel, 2009) believed to be an improvement over the old, are beginning to be used by some DHEs and are included in TxDOT HDM (2011). One DHE observed that, at least for that DHE's district, they do not demonstrate consistently better results than the older ones. This observation serves as a reminder that all the variations in watersheds even within a given region, cannot be captured with one relatively simple equation, though statistics prove that in general the OmegaM regression equations are an improvement over those previously used. TxDOT HDM (2011) recommends the use of the regression equations on uncontrolled watersheds, and preferable as a validation tool to compare with the results of other methods.

HEC-HMS is the most sophisticated hydrologic modeling option within the grasp of TxDOT DHEs. However, DHEs generally find it challenging to take the time out to develop the model given their limited experience with it and the diversity of tasks they must complete apart from modeling. Some districts do not use it at all for "in-house" projects. In one district, where the DHE (part-time) does utilize HEC-HMS with some regularity (once or twice a year), approximately two full days are required to collect all data, delineate the watershed, build the model, and generate estimates. This same DHE believes that this time could be reduced if data input options in HEC-HMS are learned and utilized.

In general, among part-time DHEs, regression equations are used not as a supplement to but as a substitute for HEC-HMS because of their ease of use. Among the full-time DHEs there is a greater level of comfort with HEC-HMS, which has the capacity for yielding more accurate results. According to one veteran hydraulic engineer who interacts with the districts, DHEs will use HEC-HMS routing if they are to design detention ponds. However, detention ponds are not commonly designed for most districts, and when they are, a consultant or help from a district with detention pond expertise is most often sought.

One of the most basic tasks in the hydrologic modeling process is defining the drainage area. At least one of the districts has vast expanses of very flat areas making the watershed divide nearly impossible to identify. That district will assume an area that seems reasonable and compare results with those of other calculations for the area that were used for earlier projects and have proven successful.

The rainfall data used by TxDOT personnel as input into hydrologic models nearly always are based on the assumption that precipitation is uniform throughout the drainage area. This assumption of uniformity leads to underestimations of runoff volumes because of thresholds and non-linearities in the rainfall-response relationship (Joseph, 2011), though other inaccuracies may either aggravate the underestimation or overcompensate for the underestimation. Indeed, all model estimations contain some degree of inaccuracy due to inaccuracies in the input data, aggregation of properties, and model structural errors introduced for the models to be simple enough for representation with a manageable source code. However, more sophisticated models coupled with data of higher temporal and spatial resolution are preferred for their greater accuracy when time and expertise allow for their usage.

Interviews revealed that HEC-HMS is more commonly used among full-time DHEs, while part-time DHEs generally rely excessively on regression equations. Interviews also suggest that at least some part-time DHEs may have inadequate time or opportunity to practice what they learn in hydrologic modeling training sessions, so that what they learn in the sessions is not reinforced or may be lost.

4.4.2.2 Hydraulic Modeling

Districts most commonly use HY-8 software for the design of culverts for small projects (less than 200 acres of drainage area), and HEC-RAS, which is more sophisticated, for bridges, bridge-class culverts, and other large culverts. HEC-RAS allows for routing a hydrograph through a channel, and the channel may be divided into multiple subsections, with additional hydrographs input at the beginning of each section.

Some culverts are designed with a "broken back," i.e., an inflection point at which the slope changes. HEC-RAS does not explicitly allow for the inclusion of broken backs for culverts, and some districts therefore prefer to use B-CAP over HEC-RAS for culvert design. However, HEC-RAS can be "coaxed" into handling more than one inflection point by treating the single culvert with multiple inflection points as multiple culverts in series, including a culvert of "zero" length at each inflection point. Some districts seem unaware of or are uncomfortable with this process.

At least one district includes counties where local regulations require that the FEMA participating community utilizes nothing less sophisticated than HEC-RAS, even for the simplest of culvert designs.

A 2008 study (Hotchkiss et al.) compares the performance of HY-8 7.0, BCAP 3.1, HEC-RAS 3.1.3, FishXing 3.0, Hydraflow Express 1.07, CulvertMaster 3.1, and Culvert 2002-2. Flowrates ranging from 10 to 300 cfs and slopes ranging from 0.2 percent to 1.0 percent were tested for a 5.0-ft diameter, 100-ft long concrete pipe culvert. None of the software was tested for broken back conditions. BCAP estimates of headwater depth were excessively high under outlet control with high tailwater, and incorrectly identified the location of hydraulic control (inlet or outlet) in almost half of the test cases. Of the eight packages, only HY-8, HEC-RAS, and FishXing correctly identified the location of control in all cases. These three packages also produced the best results overall for estimating headwater depth and outlet velocity. The authors concluded by recommending HY-8 for culvert design at stream crossings that are not hydraulically affected by upstream structures, and HEC-RAS for culverts in series or for when flows are affected by other upstream structures.

Districts that have large urban centers are more likely to have storm sewers in their design. Most of the districts, if they have storm sewers at all, have very few of them, and are likely to hire consultants to design them. The districts that do design storm sewers in-house have used WINSTORM (software developed by TxDOT) for the hydraulic design, though there may be a general shift toward use of Geopak Drainage.

Many of the districts have few if any of their own retention or detention basins, though they generally sense that such basins will become more common in the near future. One district routinely designs its own retention and detention basins, and has its own spreadsheet program, CULROUTE, which it began developing in the late 1980s.

Some districts are in the habit of not modeling open roadside channels. Possible factors contributing to this habit of not modeling may be time constraints, and the tendency for roadside channels within the particular district to capture the stormwater from the roadways only and in quantities that are not substantial. Districts that do at least sometimes model roadside channels use HEC-RAS, or, less commonly, Geopak Drainage.

HEC-RAS is typically run in steady-state mode, though flow in open roadside channels and other channels is typically not steady. Since the temporal distribution of the actual storm event is not provided as input into and utilized by the hydrologic model that generates the hydrograph for HEC-RAS, use of HEC-RAS in unsteady-state mode would not necessarily yield more accurate results.

Like hydrologic modeling, hydraulic modeling is prone to errors. One DHE stated that in most cases HEC-RAS may be adequate, but expressed a desire for two-dimensional hydraulic modeling for bridges at river bends. The literature review confirmed that two-dimensional modeling as provided by FESWMS may better predict bridge scouring in such situations (Larsen et al., 2011). TxDOT HDM (2011) recommends that the Design Division's Hydraulic Branch be contacted for such modeling because of the time and expertise required. Noteworthy is that the DHE who expressed a desire for two-dimensional modeling is a full-time DHE, not a part-time DHE. Furthermore, the avoidance of HEC-RAS in "broken back" mode was found among some part-time DHEs, but not full-time DHEs.

Interviews also suggest that at least some part-time DHEs may not have adequate time to practice what they learn in hydraulic modeling training sessions, so that what they learn in the sessions is not reinforced or may be lost.

4.4.2.3 Model Validation

Ideally, USGS continuous stream stage data and rating curves would be available at each site so that a portion of the data would be used to calibrate models, and the remaining portion used to validate the models. Unfortunately, such USGS stations are practically never at the site. Districts have been relying on one or more of three basic methods for validating their models: 1) comparing simulated values with those of other procedures; 2) comparing simulated velocities with velocities that seem to be actually occurring; and 3) comparing simulated elevations with observed elevations.

One of the DHEs interviewed discussed calculating flows, velocities and elevations using an NRCS curve number method and HEC-RAS, and then comparing calculations generated for a different project at the same site years ago (but without the land use having changed substantially) in which different methodologies had been used. The similarity of results served as some degree of validation. Other DHEs indicated use of regional regression equations as a check on results yielded by an NRCS curve number method. Having an NRCS estimate close to the regional regression estimate generates confidence that the estimated peak discharge is reasonably close to the true value. Two unpublished in-house documents, "An Example of a Complementary Comparison of Hydrologic Methods" (by David Stolpa, P.E., 2006) and "Guidelines for Validation Method 1," carefully describe procedures for validating results by comparison with those of a different methodology, particularly a stochastic approach (such as regional regression equations) versus a deterministic approach (such as an NRCS dimensionless unit hydrograph method). The procedure is practiced in at least one district and may be considered a best practice for using results from multiple methods for model validation.

In at least one District, modeling with HEC-RAS is considered to acquire validation when it yields water surface elevations for the 100-year flood that closely match the FEMA-generated 100-yr water surface elevations, if FEMA's results are based on a detailed study of the area.

Some personnel interviewed expressed that they consider simulated velocities as part of the validation process. If simulated velocities are easily high enough to cause scouring yet no scouring ever occurs, then most likely the simulated velocities are unrealistically high. Also, Asquith and Heitmuller (2009) have gathered nearly 60,000 data points from 620 USGS gauging stations in Texas, and found that mean velocity very rarely exceeds 10 ft/sec. Model results exceeding this value are suspect. Experienced personnel visiting the site to examine the channel geometry and geology may be able to discern a range of realistic velocities, and use that range to validate the simulated velocities, but there are very few personnel with such veteran expertise.

Typically, of the simulated values generated, the only one with a directly measured counterpart available is the water surface elevation. These data are helpful in validating the overall (hydrologic and hydraulic) modeling process, and is often the most important quantity of concern. DHEs use water surface elevations of historic floods for model validation.

In one district, a 100+ year flood left a high water mark on the steps to the porch of a farm. A survey crew determined the elevation so that it could be used to help validate the model used for design of a soon-to-be-let project. In that same district, a separate flood considered to be 100-yr had the shoulder at a particular point of a highway as its high water mark, and the elevation was helpful in model validation. Among TxDOT districts in general, DHEs often consult maintenance personnel to learn of high water levels of historic floods. One veteran engineer has noted that the waterline in a culvert indicates long duration low flow events on the order of the

1- or 2-year storm, though none of the DHEs explicitly identified the use of such culvert marks for model validation.

Regardless of how the historic high water data are acquired, the rain gauges in the area may be too sparsely distributed to allow for accurate estimation of the corresponding storm volume and its spatial distribution. The validating capacity of the high water mark and rainfall data to be used as model input is limited. However, in one district, after the high water level indicated by a debris line left on a tree was recorded, the DHE used the Next Generation Radar (NEXRAD) Doppler radar data available for the storm to acquire a spatial distribution of the storm, and to perhaps better validate the model. NEXRAD data dating back to the mid-1990s and covering nearly all of Texas are available through the National Oceanic and Atmospheric Administration (NOAA) Satellite and Information Service (http://www.ncdc.noaa.gov/nexradinv).

Though NEXRAD data may be helpful in estimating the spatial distribution of the storm, they are known to systematically underestimate or overestimate rainfall at particular points. Rain gauge data typically represent rainfall volumes at particular points much more accurately than does NEXRAD data. The rain gauge data are used to calibrate the NEXRAD data to develop the most accurate estimate of the total storm volume and its spatial distribution. This in turn would allow for the most accurate modeling. Presently, the process of calibrating NEXRAD data for incorporating into a model such as HEC-HMS may be beyond the resources of DHEs. However, in a lawsuit in which the plaintiffs asserted that property was flooded due to a TxDOT project, the district hired a consultant who calibrated NEXRAD data and incorporated it into HEC-HMS to demonstrate that any additional flooding due to the TxDOT projects was negligible. The district won the case.

At times, the high water elevations that occurred during floods are not known exactly, but the DHEs find the number of times which a bridge has been overtopped during a particular time period by consulting notes that may accompany (but are not a required part of) the biannual Bridge Inventory Inspection System (BRINSAP) reports. Also, the DHEs consult maintenance personnel to learn how frequently roads at culvert crossings have been overtopped during a particular time period. This historic frequency is then compared with the frequency with which the model predicts overtopping when using rainfall intensity values listed by county. However, meaningful comparison of frequencies is not straightforward because the number of exceedances per given time period will vary from one time period to the next due to random effects. A comparison of frequencies of overtopping is not as strong of a validation process as is a comparison of high water marks. The richest information will indicate high water mark elevations for many storm events, especially as the high water elevation depends not simply on the estimated storm volume, but also on the spatiotemporal distribution of the actual storm.

4.4.2.4 Structural Elements

This subsection presents various structural practices. Most of the practices are considered "best" practices. (Practices already explicitly identified in the TxDOT HDM are generally not discussed below.) Some may require more time to be proven, and may better be categorized as "sought."

4.4.2.4.1 Maintaining Road Profile Elevations in the Floodplain

Two of the DHEs interviewed expressed the importance of maintaining the road profile elevation in the floodplain. Actually, this is one of the structural practices that is explicitly identified in TxDOT HDM, but it is included here because of its simplicity and importance. Even in the case of a simple resurfacing project, the thickness of milling is to match the thickness of overlay. This practice is not to be limited to only the FEMA mapped flood zones or participating FEMA communities, but is to be applied in all flood areas. As discussed in the Complaints and Lawsuits/Mitigation section, considerable property damage may occur for which TxDOT becomes liable even in remote rural areas.

4.4.2.4.2 Entrance Weir with Culvert if Road Profile Must Be Raised in Floodplain

An FM road was expanded to include additional lanes, and the existing road profile elevation was increased by approximately 2 ft in the process. In the past, stormwater had overtopped the roadway with a high frequency, and flooding of the roadway was anticipated to continue with a fairly high frequency even with the increased elevation. The consultant therefore also replaced the existing 24 in. culvert with two 48 in. culverts. This prevented flooding of the new roadway, but caused frequent flooding of a home on the downstream of the roadway.

To both restore the downstream hydraulics for the property owner and maintain the prevention of flooding of the improved roadway, a concrete weir box with a crest elevation equal to the overtopping elevation of the pre-improved roadway was therefore constructed on the upstream side, but with a 24 in. diameter inlet to match the diameter of the culvert that had been replaced. Now, as stormwater flowrates and channel storage begin to exceed those that would have overtopped the pre-improved roadway, stormwater flows over the crest. The "overflowing" and "passing through" waters rejoin and enter the two 48 in. culverts to be carried to the other side of the roadway. The entrance weir/culvert system mimics overtopping of the existing roadway, and there is no significant alteration of backwater or tailwater effects due to the project. To date, the construction appears to be working as intended. Figure 4.1 shows the weir box structure with its crest elevation matching that of the pre-improved roadway. Figure 4.2 shows the upstream side of the two 48 in. culverts, one of which was temporarily covered during the construction phase. The 24 in. inlet is not visible, but is at the base of the wall the top of which appears along the right edge of the photograph.

Figure 4.1. Entrance Weir Culvert Structure to Mimic Overtopping of Pre-Improved Roadway.

Figure 4.2. Upstream End of Two 48 In. Culverts, Immediately Downstream of Entrance Weir.

4.4.2.4.3 Provide Sags in Roadway on Either Side of Bridges

One DHE is in the practice of providing sags in the roadway on either side of a bridge. In the event of an overtopping flood, damage will tend to occur in and near these approach sags rather than to the bridge itself, and will tend to be less costly to repair. This practice is relevant for any design event. For the 100-year event in particular, overtopping is permissible if the depth, velocity, and quantity of water allow safe passage of vehicles through the sags during the design flood event.   This flow through the sags allows for passage of water and helps prevent the 1-ft design freeboard at the bridge itself from being exceeded during the design event, and allows for a slightly smaller bridge. Also, in the event of a flood that is in excess of the design event, the backwater effects may be reduced due to the relief provided by the sags.

4.4.2.4.4 Flood-Accommodating Barrier between Opposing Lanes

As development occurs, and additional right-of-way becomes more difficult to acquire, additional lanes of a divided highway are more conveniently added to the interior rather than the exterior, thereby necessitating a barrier between the opposing sets of lanes. However, if the improvement occurs on a bridge at a stream crossing, the typical concrete barrier may cause severe backwater effects in the event of a flood that overtops the bridge. In such situations, a steel beam supported with rails, as shown in Figure 4.3, and installed in one district, provides an alternative that allows water to pass more freely but maintains protection between opposing lanes.

Figure 4.3. A Steel Beam with Support Posts Is Used instead of a Concrete Barrier for the Portion of the Divided Highway That Is within the 100-Year Floodplain.

4.4.2.4.5 Consider Maintaining Bridge Span Lengths as Means of Preserving Existing Flow Patterns

The more advanced technologies of today allow bridge spans to be much longer than in the past. However, in one TxDOT district in which a bridge was being upgraded, the DHE maintained the shorter, existing span widths and corresponding column positions because HEC-RAS modeling indicated that having fewer columns would dramatically increase flow velocities, possibly resulting in very adverse tailwater effects. A DHE from another district noted that the placement of a bridge column causes suspiciously large drops in flow velocities. With such modeling imperfections or uncertainty, the wisest alternative may be to change as little as possible what has proven adequate in the past, as did the DHE who maintained the column positions.

4.4.2.4.6 Preserving Natural Sheet Flow into Karst Aquifer Recharge Feature

A recharge feature for a karst aquifer was located between the existing embankment and edge of ROW, and received sheet flow only from outside of the ROW. The road embankment was proposed for widening such that it would cover the recharge feature. In order to allow recharge to be maintained, a TxDOT engineer designed a structural gravel layer and perforated pipe within the proposed embankment.

4.4.2.4.7 Staggered Barrel Culverts to Convey Bedload as Well as Water

One of the major problems with culverts is their tendency to fill with bedload material. In some of the drier districts where storms may be of large volume but seldom occur, upland erosion may be dramatic, and aggradation within and immediately upstream of the culvert may be problematic. In one such district, the primary maintenance task is the removal of sedimentation and debris from culverts.

Usually, gravel and other bedload material tends to accumulate in or near the culvert due to frequent, small floods rather than the rare large flood (Herrmann, 2007). The need to design large culverts to accommodate the larger floods leads to velocities that are incapable of carrying material through the culvert during smaller floods. There seems to be a conflict between transporting water and transporting bed load materials.

Staggered culvert barrels (Figure 4.5) allow for relatively high velocities to be maintained during small floods, but are still able to accommodate large floods, and resolve the tension between conveying water and conveying bed load.

The improvement to be provided by a staggered barrel approach may be illustrated by what occurred in one district where a traditional crossing had been constructed. On a road where a vertical sag was designed to accommodate the occasional passage of water of an ephemeral stream (i.e., the typical “low water crossing”), a culvert was installed beneath the sag as a relief structure to prevent long-term ponding on the upstream side. However, the combination of the sag and the underlying culvert led to the accumulation of gravel on the upstream side, and eventually the complete filling of the culvert, and a deposited gravel bed that became nearly as high as the roadway (Figure 4.4). Eventually, the altered overtopping flow dynamics caused severe erosion and structural failure on the downstream side, and the crossing had to be redesigned and reconstructed (Herrmann, 2007).

The DHE, having been informed of a staggered barrel approach, installed such a system. Figure 4.4 shows the upstream side of the site with the traditional sag/culvert system installed; Figure 4.5 shows the same upstream side two years after the staggered barrel culverts had replaced the traditional approach. No bed load material has accumulated. Furthermore, very shortly after the staggered barrel culverts had been installed but before the project was completed, a storm of moderate magnitude occurred, and much of the gravel that had accumulated upstream was washed through the culverts without causing any damage. The staggered culvert barrel system appears to be self-cleaning, as intended. Design guidelines for staggered barrel culverts are currently being developed by Cleveland and Strom under TxDOT Project 0-6549: Hydraulic Performance of Staggered-Barrel Culverts for Stream Crossings.

Figure 4.4. The Upstream Side of a Traditional Vertical Sag/Culvert Crossing with Accumulated Bed Load Material (Herrmann, 2007).

(Photograph taken March 4, 2011, by Dr. Kyle B. Strom)

Figure 4.5. The Upstream Side of the Same Site Shown in Figure 4.4, but with a Staggered Barrel Culvert System Having Been Installed for Two Years.

4.4.2.4.8 Articulated Concrete Blocks in Open Channels

All districts have both naturally occurring and constructed open channels. For naturally occurring channels, countermeasures are at times needed to prevent scouring, bank undercutting, or other erosive effects. A noteworthy technology used in at least one district to prevent erosion of a stream bed and banks is Articulating Concrete Blocks (ACBs). The term "articulating" refers to the bed of interlocking concrete units being capable of staying in contact with a shifting subgrade while remaining interconnected. Loss of contact with the subgrade is the primary criteria of failure (FHWA, 2009). The arrangement of blocks as a heavy, interconnected, flat sheet allows it to withstand high hydraulic shear stresses.

Openings in each block allow for infiltration and vegetation, and, when the blocks are installed over a significant length of the channel, result in lower peak flows than would impermeable concrete lining. ACBs have been used and studied for the past three decades (FHWA, 2009), but their recent appearance in a Hydraulic Engineering Circular, HEC-23, which was published after TxDOT HDM (2009) was released, suggests their relevance for inclusion in this report.

As far as the DHE interviewed is aware, the ACBs are performing well in tributaries to the North Sulfur River in east Texas (Figure 4.6). In the 1920s (according to the best estimate of the DHE), a large project straightened the North Sulfur River, thereby steepening the bed slope and creating high velocities and channel bed instability, which propagated upstream into the tributaries. In 2002–03, TxDOT replaced two bridges crossing two of these tributaries, and at that time the channels were badly degraded with steep, unstable banks. TxDOT, continuing to experience erosion problems after constructing the new bridges, eventually installed ACBs on the channel banks at and near the sites. Figure 4.6 illustrates that by 2008 vegetation was established. According to the DHE, the ACB system is not undermined in erosive conditions which in that district have undermined and damaged concrete lined channels.

(CSJ 1482-01-016, photograph by Howell Engineering, 2008)

Figure 4.6. Articulating Concrete Blocks Stabilize the Channel Slopes of the North Sulfur River, while Permitting Infiltration and Vegetation.

4.4.2.4.9 Miscellaneous Open Roadside Channel Practices

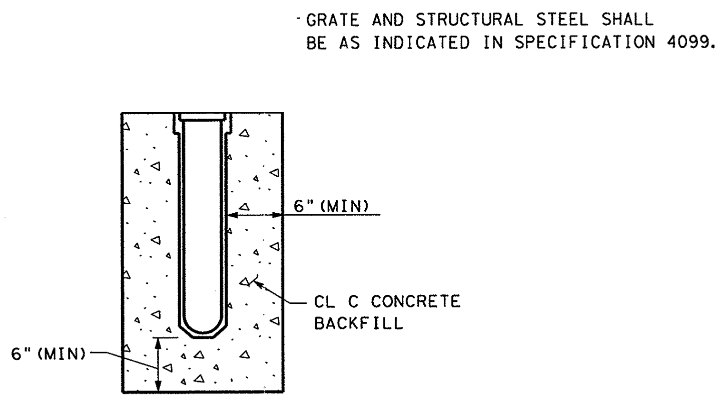
All districts rely on open roadside channels, and vegetated (grass) channels are more common than concrete-lined or other lined channels. Lining other than grass is required where velocities would otherwise cause erosion given the hydraulic shear stress capacity of the vegetation, and the tendency for the vegetation to thrive in the particular climate.

One DHE expressed that, if channel slopes are greater than 5 percent, grass lining is avoided even if such lining would be able to withstand the hydraulic shear stress. This is because machinery for removing sedimentation or for addressing other maintenance needs does not easily operate at such slopes. In general, the district always involves maintenance personnel in the design of open channels.

In at least one district, whenever channelized water exits the TxDOT right-of-way via the ground surface, the water is made to pass over vegetation before exiting to ensure a gentle non-erosive flow.

One DHE always insists on clearly indicating all designed open channel invert elevations for earthen or vegetated channels. In this way, when the time comes to remove silt or other debris, the district can easily demonstrate to environmental entities that it is merely restoring the channel to its full functioning capabilities. This same DHE uses in-line detention to accommodate excessive runoff from the TxDOT ROW.

Another interesting roadside channel system is that developed by the consultant Turner, Collie, and Braden for a high-occupancy vehicle lane with limited space for a drainage system. A grated 4 in. wide fiberglass trench drain (Figure 4.7) has been reportedly performing well since the project was completed in 2007. Figure 4.8 illustrates how this trench drain relates to the rest of the drainage system. Although this drainage system is needed primarily to carry away runoff from the pavement itself and not for off-site runoff coming into the site, one can see how, as TxDOT ROW continues to approach exhaustion, such trench drainage may provide an alternative to traditional open channels.

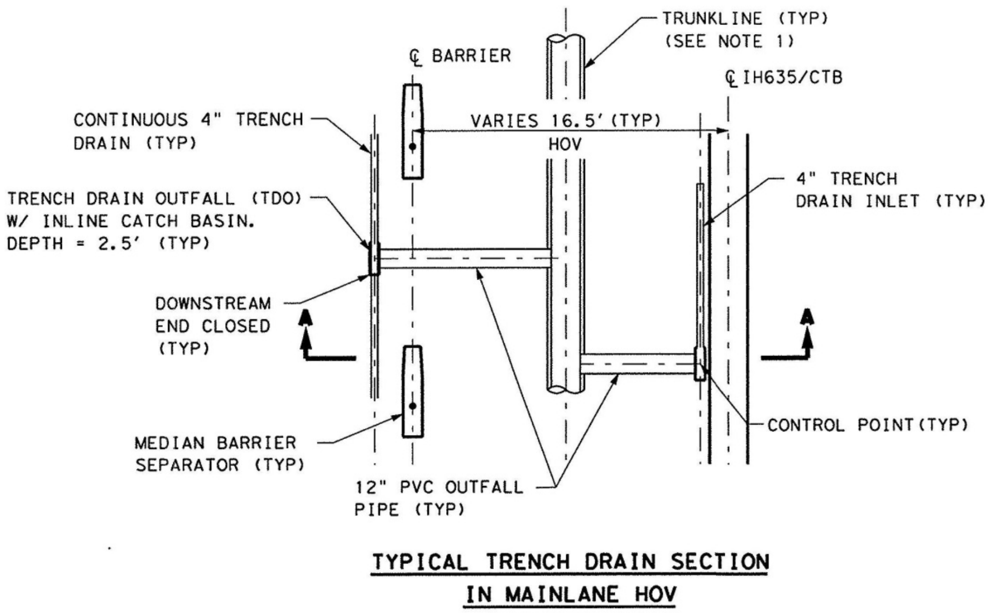


TYPICAL TRENCH DRAIN SECTION

IN-LINE CATCH BASINS SHALL REQUIRE THE SAME SECTION.

(CSJ 2374-01-153)

Figure 4.7. Trench Drain Section for a TxDOT Project in an Urban Setting with Limited Space.



(CSJ 2374-01-153)

Figure 4.8. Plan View of Fiberglass Trench Drain in Relation to Other Components of Drainage System for High-Occupancy Vehicle (HOV) Lane.

4.4.2.4.10 Driveway Sags as a Remedy to Mounding at Driveway Pipes

One DHE discovered that driveway pipes to accommodate flow through roadside ditches are sometimes installed with driveway material forming a mound above them, as can be seen by carefully examining Figure 4.9, though proposed ROW line elevations at driveways are shown in the drawings. In the event that the carrying capacity of the pipes is exceeded (which may be frequent as they may be sized for storms with a high annual exceedance probability), stormwater may flood roadway lanes or property owners' yards, rather than overtopping the driveway above the piping as intended. A tour of rural highways throughout Texas revealed that this mounding is not unique to the District of this reporting DHE. The DHE recommends that when mounding or other circumstances would likely contribute to flooding of the roadway or private property upstream of the piping, sags running parallel to the piping be designed into the driveway, such that the bottom of the sag invert elevation is not far above the top of the piping.

Figure 4.9. Mounding above Driveway Pipes Contributes to Flooding of Roadway and/or Private Property.

4.4.2.5 Maintenance

Maintenance crews are responsible for a variety of performance aspects of TxDOT infrastructure, but here we consider only the hydraulic and hydrologic performance.

In regard to maintenance issues directly related to hydrologic or hydraulic performance, maintaining culverts and open (roadside) channels free of sedimentation and debris are the tasks consuming the most time in rural areas. In urban areas, drainage related maintenance tasks become more complex and diverse, and may include cleaning of retention and detention ponds, and unclogging storm drains and storm sewer lines. In one large city, the maintenance department must struggle against environmental concerns to remove deposits and vegetation along the edge of the roadway to prevent excessive ponding of water in the travel lanes.

Maintenance budgets are developed annually based on needs and funds. Drainage-related maintenance may to some extent follow the roadway maintenance priorities. Maintenance personnel in one District explained that the District's roadways are rated by a consultant or by the Central Design Office.

Maintenance personnel have expressed the importance of cleaning or checking drains, culverts, and other critical structures immediately after each storm in preparation for the following storm.

One best practice in rural areas is to cooperate with farmers to return deposited soil in drainage ditches to their land. If vegetation has already developed on the deposited soil, it may be applied to eroded areas elsewhere in the right-of-way.

Several practices need to be developed, if possible, as solutions to maintenance problems. These problems, if left unresolved, reduce the hydrologic and hydraulic performance of TxDOT drainage infrastructure or otherwise increase adverse impacts. These problems include erosion and tree growth in vegetated canals, theft of manhole covers, cleaning out of concrete mix left by deliverers near storm drains, and violation of construction permits. In regard to vegetated canals: In at least one district, the canals or bayous have eroded such that the slopes cannot be negotiated by heavy machinery, or have developed trees that prevent the efficient usage of heavy machinery. In regard to the theft of manhole covers: Theft is on the rise as the recycling value of scrap metal rises. Tack welding to prevent the theft places an additional burden on the maintenance crew. Alternatively, to eliminate the motivation to steal the covers, Beijing has been experimenting with non-metal polymers having no recycling value since 2005 (Gardner, 2008), though the literature review for this project did not further investigate the success of such an approach. Even when a missing manhole cover does not disrupt drainage system performance, the burden to maintenance crews takes away from their time to address other drainage issues. In regard to concrete mix deliverers cleaning out their mixers near storm drains: The removal of the water-impeding hardened material from the drainage system is a formidable task. In regard to construction permit violation: Maintenance personnel also review private property sites for compliance with permits. At times the permits are not followed, and may result in drainage problems for neighboring property or the ROW. The maintenance team may need to correct the problem at its own expense, as time and money do not allow for suing the property owner to bring the modifications into compliance with the permit.

4.4.2.6 Documentation

Thorough and accessible documentation is essential for TxDOT to continue to progress as a functioning, unified entity. Refinement of practices, model validation, and other design and management decisions all depend on accessing documentation. When district personnel were asked how best to avoid a lawsuit, the most common response was "documentation." Documentation helps hold together TxDOT's various elements, as well as its past, present, and future.

Documentation during the design and construction phases may help TxDOT defend itself against future drainage-related lawsuits. Typically, for each construction project in a given district, the project manager at the district office maintains a project folder that includes sign-in sheets, meeting minutes, correspondence, and all other documents relevant to the project throughout the design phase. Districts often include hydraulic report information directly on the plans, even though the information is not needed by the contractor. This helps preserve the long-term accessibility of the information. Other important notes that may have legal implications may also be included on the plans. As was discussed in Section 4.4.1, one district was protected by a note on plans that were several decades old and reflected a city's agreement to build stormwater infrastructure that it failed to build. At least one DHE makes efforts to include imagery reflecting the state of development in the project's drainage areas.

During the construction phase, the area engineer continues to add construction progress meeting minutes, change orders, and all other construction-related documents to this project folder. This folder is to be kept for the life of the structure.

Documentation during the maintenance phase may help establish a record of high water marks, overtopping, and other information that may be used for hydrologic and hydraulic model validation. It also may help establish maintenance costs and life cycle costs so that resources for mitigating hydrologic and hydraulic impacts are optimally utilized.

During the maintenance phase of the structure, documentation is not as project-specific as in the design and construction phases. A particular culvert or roadside open channel, for example, does not have a particular folder into which all documentation relating to its maintenance is placed. Rather, maintenance personnel log their activities chronologically.

TxDOT and all other state DOTs are mandated by the federal government to inspect all bridges, whether "on-system" (of the DOT infrastructure) or "off-system" (of the infrastructure of some entity other than the DOT), every two years. All but one district hires a consultant for the inspections. In any case, the inspection documentation is stored electronically in the statewide Bridge Inventory Inspection and Appraisal System (BRINSAP) database, which allows for reviewing data by year. Interviews with DHEs indicate that the thoroughness of the inspection documentation, including photographs, is very helpful for design purposes. One of the disadvantages of BRINSAP is that the data are organized by year rather than by structure number. More recently, PonTex, an in-house system to manage bridge inspection data, has been made available to TxDOT personnel statewide through any Internet connection. It is a relational database that allows sorting by category such as structure number, or by a combination of categories. A minority of the DHEs have switched from BRINSAP to PonTex.

Districts have begun inspecting their system bridges during the "off" years of the federal inspection requirements. The resulting data are stored in the Maintenance Bridge Inspection Tracking System (MBITS). The data from PonTex or BRINSAP are not copied into MBITS, nor vice versa. Nor do BRINSAP and PonTex share common inspection data. To review the entirety of the inspection data for a particular bridge, up to three databases may need to be inspected. All three databases note the number of overtoppings since the previous inspection, and are helpful in validating hydraulic model results.

In one district, a form (Figure 4.10) is filled out to thoroughly document not only overtoppings, but any flooding which may be considered significant. This would prove helpful in the model validation process, in defense against lawsuits, and in demonstrating the need for upgraded structures. Noteworthy also is that key questions, which may at times be overlooked in an informal discussion of high water with maintenance personnel, are included in the form to ensure that they are not accidentally neglected. For example, whether the structure was partially clogged with soil or debris may have as much impact as the magnitude of the storm as to whether overtopping occurred, and is asked on the form. The form also provides redundancy to enhance data quality; the maintenance person is asked depth of water over the flooded surface, and to mark and describe the mark made at high water for later surveying. No electronic database is now being used to store the data of the form. As TxDOT continues to make more frequent use of GIS data in its modeling and design, providing geographic coordinates as part of the data record to be stored would allow for all such records to be represented as points within the watershed of concern, and thereby greatly facilitate the model validation process.

In at least one district, ditch grade lines of grass-lined open channels are indicated on drawings and otherwise recorded so that future cleaning will not be contested by environmental personnel.

HIGH WATER DATA

Date:___________________________

County:__________ Highway:_________ Control:___________ Section: ____________

Location of flooding (Stream name, distance from fixed landmark and reference marker.)

____

Was traffic stopped? No___ Yes___ If yes, for approximately how long?

____

Approximate depth of water over the road:

____

Is there a difference in water surface elevation from upstream to downstream?

No___ Yes___

If yes, approximately how much difference?

____

Approximately how much rain fell at this location, and what was the duration?

____

Was there damage to adjacent property upstream or downstream? No___ Yes___

If yes, please describe.____

____

Attach two copies of color photos.

____

Was the highway structure?

Silted___ Clogged with brush___ Clear___ No Structure___

Was the condition of the channel? Clogged___ Clear___

____

Mark the high water line so that the elevation can be determined later.

Please describe how marked.

____

If you require more space to answer any of these questions or can offer any further information, please write on the back of this form.

Signature_______________________________________

NOTE: Your account of flooding at this location could be very valuable in that you may be the only reliable eyewitness of the event. This form should be filled out when water runs over the highway or damage is done to roadbed or any time you observe what you consider significant flooding. Rev. 02/08

Figure 4.10. Form to Document High Water Event.

5. REVIEW OF STATE DOT SURVEY RESULTS AND RELEVANCE TO TXDOT

In this section, the state DOT survey results are reviewed. TxDOT itself was not included as a DOT in this survey. The relevance of survey results to TxDOT is also discussed in this section.

Appendix E displays the state DOT survey along with summaries of multiple-choice responses and a listing of written responses to open questions. Thirty-five of 49 states responded. Respondents were told that results would be published in a report in which neither they nor their state would be identified in connection with their responses. All respondents identified their state, and most provided their name under optional items #1 and #2, respectively. Unless the respondent completed all non-optional items, the survey would not be accepted by the SurveyMonkey system.

The items in the survey of DOTs generally fall into the following categories:

- Defining Adverse Impacts (items 3, 6-14).
- Mitigating Adverse Impacts (items 12-14).
- Relationship with the Local Floodplain Administrator (items 4 and 5).
- Organizational Structure of the DOT (items 15-18).
- Hydrologic/Hydraulic Modeling (items 19-22).
- Reference Materials (item 23).
- Lawsuits (items 24 and 25).
- Miscellaneous (item 26).

Each of these categories is discussed in the subsections below.

5.1 DEFINING ADVERSE IMPACTS

As discussed in Section 1, exactly what constitutes an adverse impact varies among communities and states. Furthermore, the term “adverse” is not necessarily used by the entity to refer to impacts which it nonetheless considers negative or unacceptable. In order to facilitate discussion in this report, the term “adverse” is used to refer to impacts which are discouraged or prohibited through laws, ordinances, or the policies of an agency such as a DOT. Survey items therefore explore how adverse impacts are defined by or for other DOTs by asking what the DOT considers as “unacceptable” flooding of adjacent property (#3), various conditions that the DOT “mitigates” (#7–#9, #11–#13), and when No-rise certifications or a CLOMR/LOMR may be required (#6, #10, and #11).

Reponses to Question #3 indicate that most DOTs (25 of 35) have written (formal) guidance that distinguishes between acceptable and unacceptable flooding of adjacent property due to a DOT project. Question #3 Open Responses lists both formal and informal guidance of the DOTs.

The reviewer inferred from informal guidance that the following are adverse impacts, depending on the DOT: an increase in backwater elevation of more than 0.5 ft (flood frequency not specified); less than 1 ft minimum 'freeboard' from developed property or roadway, whichever is lower (flood frequency not specified); and flooding of any insurable structure for the 100-year flood unless the 100-year flood already causes such flooding, in which case the flood depths shall not increase.

The reviewer inferred from written guidance that the following impacts are adverse, depending on the DOT:

- An increase in the probability of flooding properties upstream of any stream crossing.
- Any flooding of structures during the 100-year storm event.
- Increasing backwater elevation by more than 1.0 ft (flood frequency not specified).
- An increase in backwater elevation where flooding of structures is already occurring (flood frequency not specified).
- Flooding for the 2-year, 10-year, and 100-year storm events that exceed the pre-existing.
- Flooding for these events, though a waiver may be provided if the increase is less than 10 percent for the 2-year event and safe conveyance to tidal waters is proven.
- Any increase in flooding potential.
- Any increase in flooding due to backwater created by a culvert at design storm conditions.
- Elevation for 100-year flood higher than 2 ft below a house.
- More than 0.10 ft increase for improved properties and more than 0.5 ft increase for unimproved property.
- Flooding above the base flood elevation; any increase in 100-year flood elevation in FEMA Zone AE.
- More than 1.0 ft increase in 100-year flood elevation in FEMA Zone A or undeveloped area, unless there is existing development upstream, in which case any increase in 100-year flood elevation.

Several respondents are of DOTs that apparently have few threshold numbers such as, for example, "0.5 ft increase for unimproved property," to define adverse impacts, but rather depend on a weighing of costs versus benefits for a particular site. Designers are guided, for example, to minimize damages, and that if damages are expected to result, designers are to present documentation to justify the damage. The lack of a rigid threshold does not necessarily lessen the design effort or the cost of the project for these DOTs. For example, in one state in which ponding outside of the right-of-way may be allowed for the 50-year event, the designer must plot the water surface contour and thoroughly investigate the area to estimate what would be the extent of property damage, as the purchase of easements or other reimbursement may then be necessary. (The information for this particular example was acquired apart from the DOT Survey.)

Questions #6 and #11 ask whether No-rise certifications are required on DOT projects located within a FEMA floodplain (#6), and in areas that are NOT associated with a FEMA floodplain. Not surprisingly, as shown in Figure 5.1, such certifications are required more frequently for projects within a FEMA floodplain (dark gray) than for those not associated with one (light gray), for the 35 DOTs responding.

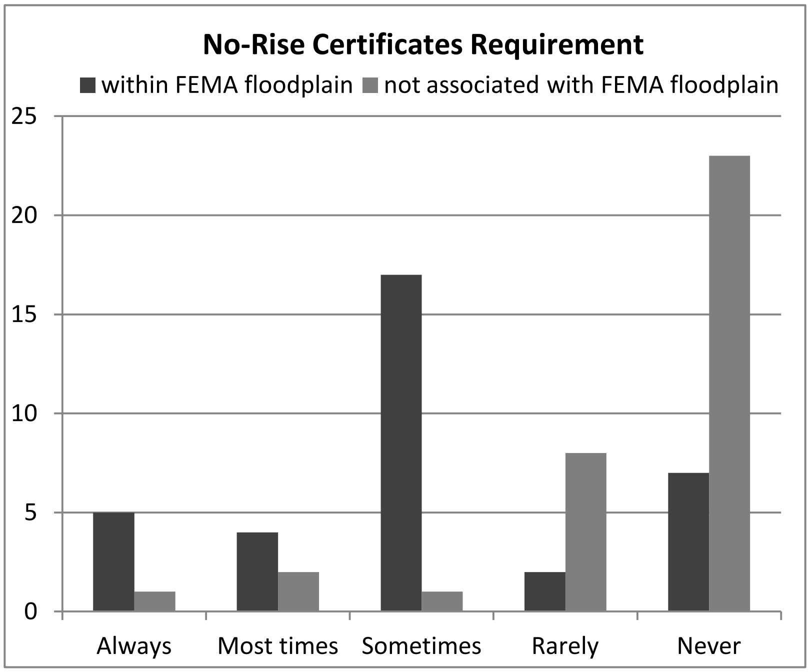


Figure 5.1. Distribution of Responses for Which No-Rise Certifications Are Required in the FEMA Floodplain (Dark Gray) and in Areas Not Associated with a FEMA Floodplain (Light Gray).

Questions #7 and #12 inquire whether the DOT mitigates water surface impacts due to DOT projects to FEMA floodplains (#7), and in areas that are not associated with a FEMA floodplain. Questions #8 and #13 are similar, but inquire into an increase in discharge. Similarly, #9 and #14 inquire into a loss of floodplain storage. Figure 5.2 illustrates that, not surprisingly, mitigation is more common for FEMA floodplains (dark gray) than for areas not associated with a FEMA floodplain (light gray), for water surface impacts, increases in discharge, and loss of floodplain storage.

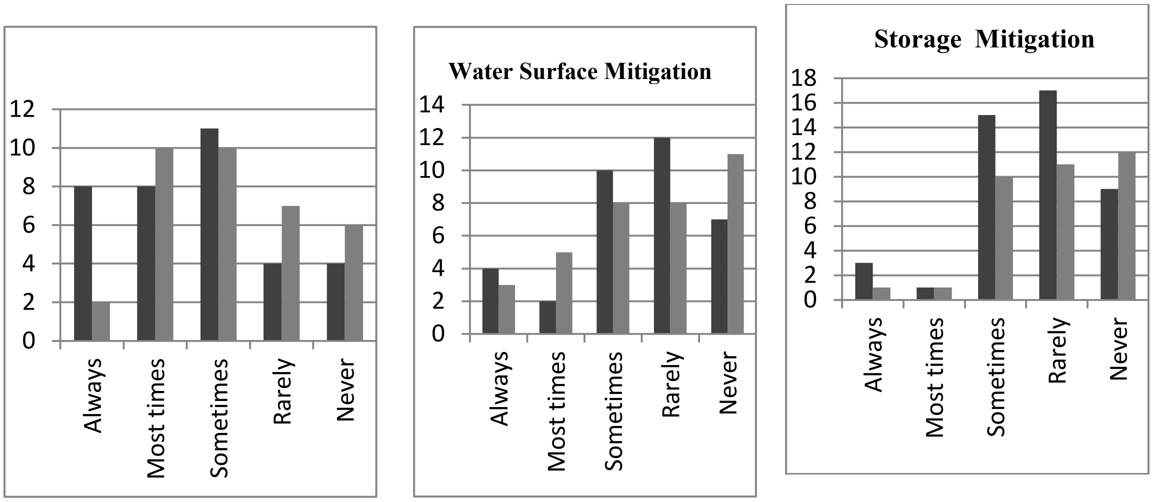


Figure 5.2. The Distribution of DOT Survey Respondents That Mitigate Water Surface Impacts (Leftmost Chart) to FEMA Floodplains (Dark Gray) and in Areas Not Associated with FEMA Floodplains (Light Gray); Increase in Discharge (Center Chart); and Loss of Floodplain Storage (Rightmost Chart).

Responses to Question #10 indicate that most of the 35 DOTs "Rarely" or "Never" prepare a CLOMR/LOMR when the project *reduces* water surface elevations, as illustrated in Figure 5.3, suggesting that a decrease in water surface elevation is generally not well-established as an adverse impact in most states. This is in contrast to an *increase* in water surface elevation in the FEMA floodplain, as the number of DOTs which "Rarely" or "Never" have to submit No-rise certifications are the small minority, as indicated in Figure 5.1.

Question #12-#14 also ask for mitigation techniques to be described by the DOTs who mitigate water surface impacts, increases in discharge, or losses in floodplain storage due to DOT projects not associated with a FEMA floodplain. Although the question anticipates structural measures, criteria that defines adverse impacts was also provided, particularly for water surface impacts (#12) and increases in discharge (#13).

Design criteria in mitigating for water surface impacts for areas not associated with a FEMA floodplain include not increasing the water surface elevation for major drainages; not increasing the flooding of buildings; keeping backwater to 1.0 ft or less above natural conditions; not allowing more than 1.0 ft of rise on any structure within a watershed of over 1000 acres; avoiding flooding of structures on adjacent property during design flood or 100-year flood; allowing no increase in runoff; and allowing no more than a 1 ft rise unless insurable buildings may be affected, in which case no worsening is allowed. In some cases the design criteria does not identify any threshold, but is to "minimize surface water impacts to the extent practicable," for example.

Design criteria for increases in discharge in areas not associated with a FEMA floodplain include not increasing peak discharge and not increasing erosion potential.

5.2 STRUCTURAL ASPECTS OF MITIGATING ADVERSE IMPACTS

Questions #12–#14 asks those DOTs who mitigate water surface impacts (#12), increases in discharge (#13), or losses in floodplain storage (#14) due to DOT projects in areas *not* associated with a FEMA floodplain to describe those mitigation techniques. Responses included design criteria as well as descriptions of structural elements. The design criteria define adverse impacts, and are therefore discussed in the last three paragraphs of Section 5.1 above. Only the structural aspects of the mitigation techniques are described in this section.

As shown in Question #12 Open Responses in Appendix E, 22 of the respondents provided a response to the request for a description of techniques used to mitigate water surface impacts due to DOT projects in areas not associated with a FEMA floodplain. Structural elements identified for mitigation of water surface impacts include excavation on the floodplain or under the bridge in overbank areas; leaving sediment ponds in as permanent detention ponds; check dams in ditches; oversizing the storm drain system to detain water; berms; maintaining road grade overtopping elevation; and making bridges larger. Nine of the 22 respondents identify the acquisition of easements or additional right-of-way as a means for addressing water surface impacts. Such land may be considered a structural element in the sense of physically occupying space, even if not used to accommodate a structure such as a constructed channel.

As shown in Question #13 Open Responses in Appendix E, 21 of the respondents provided a response to the request for a description of techniques used to mitigate the increase in discharge due to DOT projects in areas *not* associated with a FEMA floodplain. However, one of these states that mitigation is not based on discharge, so that only 20 actually describe techniques. Structural elements were described in only very general terms. Those listed include ditch storage; detention ponds/basins; retention ponds; channel improvements; internal and external energy dissipaters; and bank protection structures. Acquiring easements or additional right-of-way was listed by four of the 20 respondents.

The summary data for Question #14 in Appendix E indicate 16 responses for the open portion of this question. However, of these, six are merely expressions that the loss of floodplain storage is not considered a significant issue. The remaining eight indicate that the DOT actively addresses or at least checks for loss of floodplain storage. Structural techniques include removing old roadway fill and excavating natural ground. Longitudinal encroachments may require the steepening of slopes, and "retaining walls and/or equalization pipes may be required to maintain the floodplain connection to the other side of the road." Two respondents identified the acquisition of flood easements as a technique for mitigation, but did not provide details as to how such easements have been used.

5.3 RELATIONSHIP WITH THE LOCAL FLOODPLAIN ADMINISTRATOR

Questions #4 and #5 explore the relationship between the DOT and the local Floodplain Administrator (FPA). Figure 5.4 represents responses to Question #4, and indicates that only 10 of the 35 DOTs "Never" apply for floodplain permits from the local Floodplain Administrator. Responses to Question #5 indicate that most of the responding DOTs (26 of 35) have a procedure for coordinating with the local FPA.

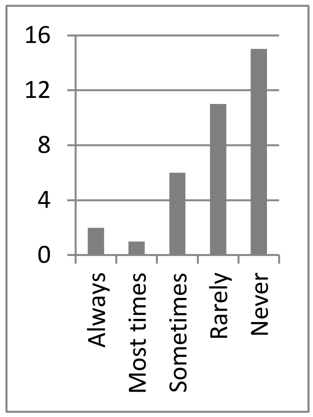


Figure 5.3. Frequency with Which the 35 Responding DOTs Prepare a CLOMR/LOMR when the Project Reduces Water Surface Elevations.

The DOT procedures for coordination with the local FPA are in "Question #5 Open Responses" of Appendix C. TxDOT HDM (2011) discusses that, based on a series of Texas Attorneys General rulings, state agencies are prohibited from applying for permits from subordinate jurisdictions. TxDOT, then, is not to apply for permits from the local FPA. However, TxDOT values coordination with local FPAs, and responses by those DOTs who "Never" apply for permits yet answer "Yes" to indicate that they have a procedure for coordinating with the local floodplain administrator may be of special interest to TxDOT. These responses are highlighted in yellow under "Question #5 Open Responses" of Appendix E. One such response indicates that local floodplain administrators are simply notified of any activities, while another response indicates that they are "contacted at the initiation of the project, and consulted for their knowledge of the project, and for recommendations." The remaining responses of the DOTs who "Never" apply for permits and yet answer "Yes" to Question #5 are actually descriptions of coordination with entities other than the local FPA.

A review of all the responses describing coordination indicates that nine of the state DOTs have a Memorandum of Understanding or other arrangements in which they coordinate primarily with a third party, rather than directly with the local FPA. This third party is usually a state entity that already has the addressing of environmental and/or water resources issues as its role. TxDOT itself entered into a Memorandum of Understanding with the Texas Natural Resources Commission (later restructured as the Texas Commission on Environmental Quality), which was then the State Coordinating Office for the NFIP, in 1998. In that MOU TxDOT agrees to provide design information and data to NFIP participating communities upon request, and to follow basic FEMA requirements. This MOU is still in effect, but with the Texas Water Development Board, which was named the new State Coordinating Office in 2007. Steps described for coordination with the local FPA in TxDOT HDM (2011) exceed what TxDOT has agreed to in the MOU.

One respondent indicates that they "do not have any local floodplain administrators." This response is likely due to an unintended interpretation of Question #5.

Sixteen of the responses indicate direct coordination with the local FPA. Of these, one mentions physically meeting with the FPA. This one states that they have "…good success on meeting with them out in the field for complex projects." Another does not mention a physical meeting, but states that the local FPAs are "consulted for their knowledge of the project, and for recommendations." The majority of the respondents for DOTs who coordinate directly with the FPA do not mention anything more in the relationship than submitting documents "for approval," or simply "notifying" them of activities in the zoned floodplain. While a lengthier survey would likely review more to the relationship, the reviewer is left with the impression that for most DOTs a dynamic sharing of insights is not prominent in the coordination process.

One of the DOTs that directly coordinates with the local FPA has established an Office of Environmental Stewardship, which among other tasks, provides educational outreach to the public regarding environmental stewardship and coordinates with the local FPAs during project planning.

5.4 ORGANIZATIONAL STRUCTURE OF THE DOT

Questions #15–#18 concern the structure of the DOT in regard to hydraulic engineering. Question #15 asks if the DOT has a hydraulic engineering unit. If the answer is "Yes," the respondent is asked to identify the type of unit. Figure 5.4 illustrates the responses.

Question #17 asks if all districts within the DOT have a hydraulic engineer who is responsible for addressing hydraulic issues. If the answer is "Yes," the respondent is asked to state whether hydraulics is a full-time function. Figure 5.5 illustrates the responses. Interestingly, of the 13 DOTs having a hydraulics engineer in each district, nearly all of them (12) indicate that hydraulics is a full-time function.

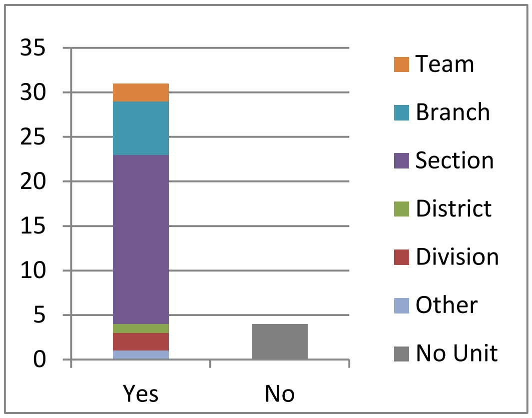


Figure 5.4. Whether DOTs Have a Hydraulic Engineering Unit and if so, the Type of Unit.

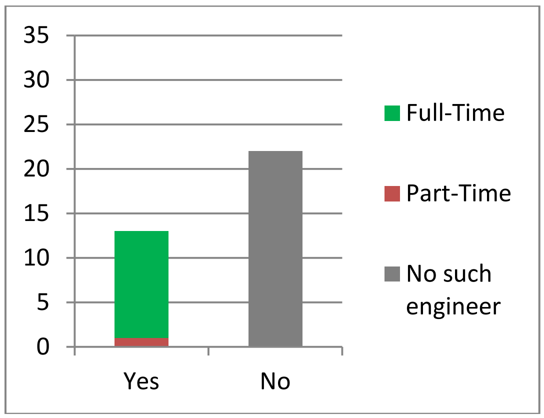


Figure 5.5. Whether Responding DOTs Have a Hydraulic Engineer Responsible for Hydraulic Issues in Each District and if so, Whether Hydraulics Is a Full-Time Function.

5.5 HYDROLOGIC/HYDRAULIC MODELING

Questions #19 - #22 concern hydrologic and hydraulic modeling. An awareness of general trends in hydrologic and hydraulic modeling practices among DOTs throughout the United States allows TxDOT to ensure that it is engaging in standard engineering practice, or better. This is important from a legal perspective. For example, federal law prohibits encroachments in the regulatory floodway of NFIP participating communities "…unless it has been demonstrated through *hydrologic and hydraulic analyses performed in accordance with standard engineering practice* that the proposed encroachment would not result in any increase in flood levels within the community during the occurrence of the base flood discharge…" (44 CFR 60.3.d.3). If the flooding would have been foreseeable through standard engineering practice, use of a substandard practice would not likely be accepted as an excuse for not foreseeing the flooding, as suggested by the literature review of inverse condemnation cases. Surveying DOTs may also provide ideas for improvement that well exceeds minimal legal requirements.

Questions #19 and #20 ask whether the DOT uses simple software (such as HY-8) or complex software (such as HEC-RAS), for non-bridge class culverts and bridge class culverts, respectively. Figure 5.6 shows the distribution of responses for these two questions. Most DOTs use the simpler software for non-bridge class culverts and the more complex software for bridge class culverts. This is consistent with TxDOT's practice. As discussed in Section 4, HEC-RAS is commonly used for more complex projects in TxDOT.

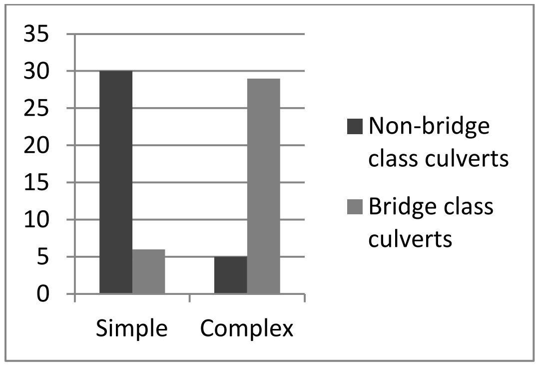


Figure 5.6. Distribution of Responses to DOT Survey Questions #19 and #20, Concerning Usage of Simple and Complex Software.

Question #21 asks whether the DOT has standardized its software such that all its hydraulic engineers use the same software. Slightly more than half (18 of 35) of the responding DOTs responded "Yes." The respondents who are of DOTs that have standardized their software usage are asked to identify those advantages and disadvantages. These appear under Question #21 Open Responses of Appendix E. The following are listed as advantages:

1. Easier to ensure that all staff have updated, thoroughly tested versions.
2. Easier to ensure that all our consultants are designing bridges and culverts in a similar fashion, and provides for a consistent process in receiving and reviewing designs from the consultant community, which also is able to work more effectively because it does not have to use different software for different districts.
3. Quality Assurance and Hydrology & Hydraulics reports are much easier.
4. Institutional expertise in the software is easier to develop.
5. Training of staff is more uniform.
6. When the standardized software is public domain software, the process of being aware of and addressing bugs, as well as receiving training from the NHI is more efficient.

Only one respondent listed a disadvantage to standardizing the use of software: the lack of flexibility to use different models where appropriate.

All 35 respondents provided a response to Question #22 (regarding model validation strategies), but some simply state "no," that they do not have strategies for model validation, or otherwise did not list any such strategies. Twenty-seven did list strategies, which fall into three basic categories: 1) comparison with historic flood elevation data; 2) comparison with FEMA data or with results from other models; and 3) comparison with scour observations.

Sources of historic flood elevation data include maintenance personnel or local residents who identify high water marks, which may in turn be surveyed. Local officials may also have records of high water elevations. Bridge maintenance records are listed as yet another source. For small streams at culverts, elevations are typically unavailable, but maintenance personnel may be consulted regarding overtopping, which, in turn, provides a lower bound for the water surface elevation. More than one respondent acknowledges that, ideally, USGS stream gage data should be used, but such data are rarely if ever available even for larger crossings. One respondent indicates that the hydraulics section "routinely checks USGS, USACE, TVA, and FEMA studies, data, and reports as well as compare to survey data on high water marks and local residents' testimony and field conditions observed at the structure during the design process."

A few of the respondents indicated that they validate by comparing simulated results of more than one model. For hydrology, results of regional regression equations, the Rational method, and TR-55 are compared, though one respondent indicated that sometimes TR-55 can be "way off." For hydraulics, HEC-RAS and HY8 may be compared. Matching simulated values to those provided by FEMA, when available, appears in four responses.

One respondent included comparison with observed scouring in the validation process, as simulated elevations in hydraulic models correspond to particular cross-section velocities, which in turn can, at least in theory, predict scouring. Another respondent considers "channel geomorphic properties during hydrological studies," which should help define a realistic range of velocities.

5.6 REFERENCE MATERIALS

Question #23 Open Responses in Appendix E lists various reference materials that are most useful to the central office in formulating design and/or maintenance policies regarding drainage systems of DOT facilities. All 35 respondents provided a response, though some were very general, such as "Federal manuals" or "research."

The following publications were identified at least once by name: Hydraulic Engineering Circular (HEC) 14, 18, 20, 21, 22, 23, and 25; AASHTO Highway Drainage Guidelines; AASHTO Model Drainage Manual; and USDA Urban Hydrology for Small Watersheds (TR-55).

Respondents often listed an institution or agency as a resource for publications, rather than a lengthy list of particular publications. The FHWA, AASHTO, USGS, and NCHRP were each listed by at least two respondents in this manner, with the FHWA listed by the most, 10. USACE, USDA, NOAA, and BLM were also listed once in this manner.

Nine respondents listed manuals developed by their own DOTs as sources of information. Two respondents stated the manuals from other DOTs were also helpful, but neither identified the particular state(s) to which any of the helpful manuals belong.

5.7 LAWSUITS

According to responses to Question #24, most DOTs (22 of 35) have NOT been successfully sued for an issue related to flooding or drainage in the last 10 years.

Question #24 also asks those DOTs, which had been successfully sued in a drainage-related lawsuit, to describe what happened and how it might have been avoided. Ten respondents provided the requested description.

Lawsuits were due to actual or at least alleged extreme increase of flow; flood damage to a house and other buildings; an expansion of the floodplain that forced private home owners to purchase flood insurance; and incorrect surveying.

Respondents indicate that the DOT would have been able to defend itself if it had been aware of the effects of raising roadway grade; centralizing hydraulic studies because they were done too infrequently and less competently at the district level; establishing a better review policy; being more diligent in the design of smaller structures; not ignoring the check storm (flood) for culvert design; and maintaining existing drainage patterns/paths.

One respondent expressed that in their state, developers may push for a jury trial when they are confident that the technical issues will likely not be understood, in which case the jury will typically award ½ of the developers' claim amount.

Question #25 inquires as to how often the DOT claimed sovereign immunity to successfully defend itself in drainage-related inverse condemnation lawsuits. Figure 5.7 shows the distribution of responses. More than half the respondents (20 of 35) do not know, and two indicate that they have had no inverse condemnation claims made against them in a lawsuit. A small portion of the respondents (4) indicate that they are of DOTs in which sovereign immunity plays a substantial role in providing protection, as indicated with the response "Most times."

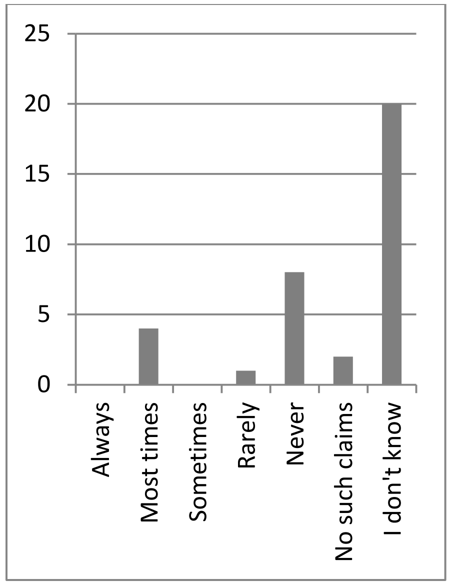


Figure 5.7. Distribution of Responses to DOT Survey Question #25, Concerning Frequency of Reliance upon Sovereign Immunity in Cases of Inverse Condemnation.

One reason for the large number of "I don't know" responses is that, even when sovereign immunity is being used as a defense, the actual term will not necessarily be used. For example, in several Texas appellate court cases in the literature review, the phrase "plea to the jurisdiction" was used by the defense to assert the implications of sovereign immunity, while the term "sovereign immunity" appears less frequently, if at all. The general lack of involvement of hydraulic engineers in legal proceedings may further contribute to lack of awareness of the use of sovereign immunity, which, therefore, may be invoked more frequently than as suggested in Figure 5.7.

5.8 A CLOSER LOOK AT MASSACHUSETTS AND NEVADA

States vary in what they consider to be adverse hydrologic or hydraulic impacts, as is suggested by the varied responses to the state DOT survey in Appendix E. As TxDOT continues to shape its policies for defining and mitigating adverse impacts, review of how other particular states and their DOTs define and mitigate adverse impacts may prove helpful. The following subsections review relevant documents from two states which, based on survey responses, appear to have widely different definitions of adverse impacts—Massachusetts, which provides a stricter than average definition of adverse impacts; and Nevada, which provides a rather loose definition of adverse impacts.

5.8.1 Massachusetts

Like all state DOTs, MassDOT must meet the minimal NFIP requirements. A key source of additional requirements and therefore of adverse impact definitions is the Wetlands Protection Act (WPA) Regulations, which are found in Title 310, Section 10 of the Code of Massachusetts

Regulations (CMR). The Massachusetts Department of Environmental Protection is given the authority to promulgate these regulations by Massachusetts General Law Chapter 131, Section 40, The Wetlands Protection Act. Although the WPA Regulations are aimed at the preservation of water *quality* and ecosystems, this aim necessarily involves water *quantity* issues of concern in this report. In particular, under paragraph 10.05(k) of the WPA Regulations we find the following requirements, which are 3 of the 10 Standards from the Policy that were incorporated into the WPA Regulations:

- **Standard 2**: Stormwater management systems shall be designed so that the post-development peak discharge rates do not exceed pre-development peak discharge rates. This Standard may be waived for discharges to land subject to coastal storm flowage as defined in 310 CMR 10.04.

- **Standard 3**: Loss of annual recharge to ground water shall be eliminated or minimized through the use of infiltration measures including environmentally sensitive site design, low impact development techniques, stormwater best management practices, and good operation and maintenance. At a minimum, the annual recharge from the post-development site shall approximate the annual recharge from the pre-development conditions based on soil type. This Standard is met when the stormwater management system is designed to infiltrate the required recharge volume as determined in accordance with the Massachusetts Stormwater Handbook.

- **Standard 7**: A redevelopment project is required to meet the following Stormwater Management Standards only to the maximum extent practicable: Standard 2, Standard 3 … A redevelopment project shall also comply with all other requirements of the Stormwater Management Standards and improve existing conditions.

These standards apply to the following, under paragraph 10.02 of 310 CMR 10:

(a)	Any bank,		the ocean
	any freshwater wetland,		any estuary
	any coastal wetland,		any creek
	any beach,	bordering	any river
	any dune,	on	any stream
	any flat,		any pond
	any marsh,		or any lake
	or any swamp		

(b) Land under any of the water bodies listed above
(c) Land subject to tidal action
(d) Land subject to coastal storm flowage
(e) Land subject to flooding
(f) Riverfront area

As discussed in Mass Highway's *Project Development and Design Guide* (2006), the designer must be aware that such requirements apply not only to the surface runoff from the roadway, but also to how the project may affect the drainage patterns in the surrounding area.

In regard to Standard 7: Often the MassDOT project is a redevelopment project. The Massachusetts Department of Environmental Protection (DEP) recognizes several constraints that make compliance with all the standards difficult. As discussed in Mass Stormwater Handbook, Ch. 3, these constraints are primarily a lack of space and the relative impermeability of the soil. The lack of space often occurs because of the presence of existing structures, including subsurface sewage disposal systems, infrastructure of various utilities, etc., as is expected in developed areas. And soils, which may have been compacted by buildings and heavy traffic, may have reduced permeability.

Impacts and how they are mitigated in culvert design are reflected in Mass Highway's *Project Development and Design Guide* (2006) instructions regarding culvert design. The allowable headwater (AHW) elevation is to be non-damaging to upstream property. A freeboard of at least 2 ft is desired between the AHW and the roadway overtopping elevation, but the AHW elevation is equal the elevation at which flow diverts around the culvert. The engineer is to consider the need to create lower-than-existing headwater ponding in flood-prone or sensitive areas upstream from the culvert. The designer is to also consider that the consequences of debris, and overbank flooding and resultant overtopping at a roadway low point away from the culvert location.

The strictness of the adverse impact definitions in Massachusetts may increase the cost of MassDOT projects, but also likely protects MassDOT infrastructure from private, municipal, and county activities in the watersheds of the MassDOT projects.

Retention/detention facilities are used by MassDOT to reduce peak discharge or other quantity impacts. Such facilities can be a breeding ground for mosquitos. Chapter 5 of the Mass Stormwater Handbook states that all stormwater practices designed to drain do so within 72 hours to reduce the number of mosquitos that mature to adults. If the practice is designed to permanently include wet pools, then mosquito breeding is to be limited by providing mosquito predators.

The Mass Highway Storm Water Handbook (2004) provides a process for successively reducing the number of design alternatives from those that are feasible, to those that are suitable, and finally to the optimal, though in the larger context of Best Management Practices that address water quality issues. The "Macro" approach, which views the performance of the drainage system as a whole rather than performance of individual components, is considered for mitigating impacts. This allows for greater design flexibility than does considering components in isolation, and would allow for a design that has an overall lower cost.

5.8.2 Nevada

As indicated in Nevada DOT's *Drainage Manual* (2006), the Nevada Supreme Court adopted the rule of "reasonable use" in 1980:

> This rule of reason provides that in effecting a reasonable use of land for a legitimate purpose, a landowner or user, acting in good faith, may drain surface waters and cast them on a neighbor's land if: (a) the injurious flow of waters is reasonably necessary for drainage; (b) reasonable care is taken to avoid unnecessary injury; (c) the benefit to the drained land outweighs the gravity of harm inflicted upon the flooded land; (d) the drainage is accompanied, where practicable, by the reasonable improvement and aiding of normal and natural systems of drainage in accordance with their reasonable carrying capacity; and (e) where no natural systems of drainage are available, the drainage is accomplished by the use of a reasonable, artificial system of drainage.
>
> Id. at 503. Various factors for consideration of each case enunciated by the court are: the nature of the land, soil and terrain; the types of surface water involved; the availability of natural drainage ways; the feasibility of artificial drainage systems; the uses to which the land has been and will be put; the benefit and the harm produced by the drainage; and a host of environmental and social concerns. The reasonable use rule allows for the careful consideration of each of these public and private concerns; growth and urbanization are not unduly restricted, but merely tempered with elements of order, planning and reasonableness.

The qualitative, subjective nature of Nevada's reasonable use rule leads to guidance in the Drainage Manual that is, not surprisingly, general and not rigorously defined. The designer is to consider questions loaded with subjective terms, such as "Is the change in the flow patterns of water *reasonably necessary*?", and "Has *care* been taken to avoid *unnecessary* damage to adjacent landowners?" The subjectivity of such terms appears likely to make private property vulnerable to NDOT projects, and NDOT infrastructure vulnerable to activities on neighboring properties or throughout the municipalities and counties, and would seem to increase the frequency of litigation.

The NDOT Drainage Manual does not explicitly provide procedures for balancing impacts against optimally minimized costs, but provides a lengthy list of FHWA, AASHTO, and other design publications with convenient links for downloading.

6. CONCLUSION/RECOMMENDATIONS

Based on the surveys and/or interviews of TxDOT DHEs and maintenance and other TxDOT personnel, state DOTs, and FPAs, all considered in light of the literature review and insights from the TxDOT monitoring committee for this project, this report concludes with the recommendations discussed below.

6.1 DEFINING ADVERSE IMPACTS

Undesirable hydrologic and hydraulic impacts are what drives the design and inclusion of drainage systems in TxDOT construction projects. A fundamental question for TxDOT to answer, then, is what impacts does it wish to formally define as adverse through its policies. A minimalist approach may be to simply follow what federal and Texas state laws define as adverse. Toward the other end of the spectrum, TxDOT may wish to observe any "No Adverse Impact" (NAI) approaches adopted by local communities. These NAI approaches will vary by community, but the "strictness" of state DOTs such as MassDOT, as discussed in Section 5.8, provide a general sense of what might be considered adverse impacts in local communities, as well as the obstacles and strategies involved in mitigating them. We recommend that TxDOT at least adopt a favorable stance toward the NAI approach for the following three reasons:

> *Interviews and surveys of TxDOT personnel suggest that TxDOT drainage infrastructure may be burdened by relatively unchecked development, particularly in emerging urban centers. TxDOT has no authority to control such development. However, the development of the strict but reasonable quantifiable measures of an NAI approach within local communities would protect TxDOT infrastructure from the hydrologic and hydraulic impacts of such development. Developers would better anticipate requirements for tying into TxDOT drainage infrastructure. To encourage such NAI development, TxDOT would likely need to be poised to observe proposed aspects of the local NAI approach.*
>
> *As in other states, the degree to which state agencies in Texas are protected by sovereign immunity has varied through the decades, and continues to evolve. Furthermore, any plaintiff may press for legislative waiving of any relevant sovereign immunity for a particular case at hand. A community with a carefully considered NAI approach incorporated into its ordinances may prove successful as such a plaintiff, but would have little justification for suing TxDOT if TxDOT itself practices an NAI approach.*
>
> *An appreciation for the NAI approach may improve the working relationship TxDOT has with FPAs and other local officials. Such alliances may prove helpful in developing the political will to address common drainage-related problems, such as the theft of manhole covers and the rinsing of concrete mixers into storm sewer and other drainage structures.*

In adopting or being favorable toward an NAI approach, TxDOT must also be aware of limitations. In particular, defining any net reduction in the amount of recharge to an underlying aquifer as an adverse impact may leave TxDOT unable to fulfill its commitment. The TxDOT ROW is largely paved, and the presence of other utilities and soil that has reduced permeability due to various forms of traffic may leave some reduction practically unavoidable, as has been expressed in the Massachusetts Stormwater Handbook (2004).

Ordinances which may require drainage systems to be designed to accommodate a drainage area with runoff that would result if the area were 100 percent developed (in anticipation of future growth), as discussed by the FPA from one Texas community, may also be impractical for TxDOT to follow. Such a requirement could lead to oversized culverts that allow for the accumulation of bed load material at and near the culvert entrance. It is not clear whether such an ordinance is necessarily consistent with the NAI approach, which, as discovered in the literature review, is based on the time-honored common law principle that what one does on their own property must not harm another's property. If such an ordinance is in combination with a watershed wide detention requirement for all future development, consistency with the NAI approach appears even less clear.

6.2 COORDINATION WITH FPAS

TxDOT HDM (2011) has specific guidelines for coordinating with FPAs. This detailed guidance was not provided in earlier TxDOT HDM editions. Interviews with FPAs indicate that in some cases these guidelines, if followed, will noticeably improve coordination with FPAs. Guidelines may additionally need to specify that only the DHE is to coordinate with the FPA, as coordination through a consultant will not necessarily be in the best interest of TxDOT.

Another possible cause for failure to coordinate is that the FPA is less prominent and lies somewhat hidden behind the community's public works department. The FPA who had not been contacted by TxDOT in 10 years offered that TxDOT "might be working through the city" instead as a possible explanation. Guidelines may need to emphasize that such work with officials must not serve as a substitute for the FPA coordination and may need to direct DHEs toward the most current listing of FPAs.

6.3 SITE VISITS

All design now occurs through the District Office of each district, with each district covering an average area of 1,100 square miles. Realistically, there may be time for no more than one visit to the typically distant project site during the design phase. As is the practice in at least one district, key design and survey personnel gather together to exhaust the information in Google Earth plan view and roadway images, and then carefully plan the site visits accordingly. While at the site, as is the practice for at least one DHE, an abundance of photographs are taken, including ones of buildings and property with a view toward risk assessment, even if that assessment is to be merely qualitative. Subtle issues must be sought. For example, we recall from Section 4.4.1 the farmer who altered the direction of his crop rows, thereby altering the drainage regime and leading to the complaint that the TxDOT project had contributed to flooding of his property.

6.4 MODELING

6.4.1 Data for HEC-HMS

Interviews suggest that most districts rely excessively upon regression equations because they are not comfortable with HEC-HMS, and because HEC-HMS is too time-consuming to "set up." Finding, downloading, and processing the appropriate elevation, land use and soil data and then delineating the drainage area may constitute the bulk of the time required to establish the model. Furthermore, at least two DHEs stated that an obstacle to using HEC-HMS has been finding the data, which seemed so accessible in the training session demonstrations. TxDOT may wish to have the Hydraulics Branch (but perhaps with additional personnel) to perform this preliminary work at the request of the DHE who identifies for that expert the location of the outlet point(s) of concern. The resulting "set up" model could then be delivered to the DHE via e-mail or ftp site, who in turn would fine-tune it to the historical flooding data and any site characteristics with which the DHE would become familiar through the site visit and other data-gathering efforts.

6.4.2 Instilling Understanding of Models

The utilization of software to execute models is no substitute for understanding the models. A not uncommon observation is that the hydrologic or hydraulic modeling software is used without an adequate understanding of the underlying methodology and the output. TxDOT may wish to encourage the use of pen-and-paper approaches for the development of hydraulic engineering skills in trainees. At least one DHE requires this of their new trainees.

6.4.3 Standardization of List of Models and Software Packages to Be Used

Interviews with TxDOT DHEs reveal that the model and software usage among them is fairly uniform, and the list is nearly standardized de facto. Maintaining or refining a standard list may be more important to allow a designer to thoroughly understand and learn a small set of software. This also allows designers to take advantage of one another's expertise. Section 5.5 lists other advantages for standardizing. A few of the districts use reputable proprietary software which may provide worthwhile advantages that are to be weighed against the advantages of reputable open source software. BCAP is in use in some districts, but modeling broken back culverts through "coaxing" HEC-RAS must continue to be promoted, as there is no more appropriate software. This "coaxing" is apparently a complicated process. An alternative would be for TxDOT, in coordination with FHWA, to alter the source code for easier accommodation of broken back culverts.

6.4.4 Model Validation

Strategies for verifying the reasonableness or the results of hydrologic and hydraulic models, in the absence of a stream gauge at the point where streamflow is simulated, are discussed in Section 4.4.2.3. They include comparing results from different methodologies; comparing the simulated velocity to those typically found for Texas streams; comparing simulated flood elevations with those recorded as high water marks; and comparing the frequency of historic overtopping with that predicted by the model. Model validation is to be encouraged through the comparison of results from distinct methodologies, in accordance with the procedure outlined in the two in-house TxDOT documents introduced in Section 4.4.2.3. In this procedure, results from the best available stochastic tool (e.g., the new OmegaEM equations as of this writing) are to be compared with those of the best available deterministic tool (e.g., HEC-HMS), in light of observed data.

Improving the quality of input data or observed data can be helpful in validating the modeled response of a drainage area to storm events. In regard to input data, if time and expertise are available, NEXRAD multisensor precipitation estimate data (i.e., NEXRAD data, which have been calibrated to rain gauges) may be provided as input data such that model output better matches observed conditions. In regard to observed data, an example of improving the observed data quality is that of the "High Water Data" sheet presented in Section 4.4.2.6. It gathers information that would be preferred for model validation primarily for two reasons:

> *The actual stage of the flood may be determined from the data, not simply whether overtopping occurred.*
>
> *Silting and clogging are noted for the highway structure and/or channel, and thus may help explain discrepancies between the model's stage estimate and the observed stage estimate.*

State DOT surveys revealed no additional strategies to those practiced by TxDOT DHEs.

6.5 STRUCTURAL ELEMENTS

Sections 2.4.1 and 2.4.2 of the Literature Review identify key structural elements for drainage systems, and suggest that, as much as practical, infiltration and storage runoff measures are to be dispersed throughout the landscape (instead of having large volumes of stormwater collected at a single outlet), with the goal of matching runoff volumes and peaks to those of predevelopment conditions.

Though nearly all TxDOT DHEs indicated in the electronic survey that they were aware of no noteworthy solutions in their districts, personal interviews and e-mail correspondence with them surfaced many solutions that the authors consider noteworthy. In regard to structural elements, these solutions are listed in Section 4.4.2.4. They include staggered barrel culverts; articulated concrete blocks; a special weir box to mimic overtopping of existing road so that the proposed increase in the road profile would not alter upstream or downstream hydraulics; a steel barrier between opposing lanes in a floodplain and specially designed to accommodate flooding; a structural gravel layer and perforated piping to accommodate the passage of sheet flow into a karst aquifer recharge feature; a fiberglass-lined concrete trench drain for a very tight space; and others. These items are recommended for inclusion in the repertoire of elements for TxDOT drainage systems.

6.6 DOCUMENTATION FOR MODEL VALIDATION, MAINTENANCE DECISIONS, DRAINAGE SYSTEM DESIGN, AND FOR THE GENERAL COHESIVENESS OF TXDOT

Readily accessible documentation is like a threading that enables TxDOT to function as a cohesive whole. Districts are at various levels of sophistication in terms of providing such documentation to employees working within the district. As TxDOT seeks to coordinate the various types of expertise throughout the state, the need for readily accessible documentation not only at the district level but also at the state level increases.

More extensive documentation would be helpful. The "High Water Data" of Section 4.4.2.6 is worthy of adoption in all districts not only for model validation but also for assessing the performance of structures, though the format may vary. Also, presently, maintenance crews record the time spent on maintaining structures by type, but not by ID. Assessing whether particular tasks should be performed in-house or by contractors is difficult to determine. Furthermore, life cycle costs become difficult to discern without such documentation, and optimizing the design of the drainage system becomes more difficult.

6.7 OVERVIEW TABLES FOR IDENTIFYING AND MITIGATING ADVERSE IMPACTS

Overview tables are recommended to assist DHEs in quickly identifying and mitigating potential adverse impacts for particular projects. Various items presented in the table may be provided as links, such that clicking the link leads to more detailed information regarding that item.
Table 6.1 is an example of such a table focused on the structural elements worthy of consideration for mitigating impacts. Items to be clicked would include, for example, "44 CFR 60.3," "Maintain road profile elevation," "boxed weir culver," etc. Similar tables would be developed for required coordination, modeling, and other themes. Other DOTs may be invited to participate.

The column of relevant state or federal statutory law is based on the literature review, is not necessarily exhaustive, and is not intended as a substitute for legal counsel. Additionally, TxDOT or any of its districts may wish to include local criteria.

Table 6.1. Overview Table for Consideration of Structural Elements for Adverse Impact Mitigation in TxDOT Replacement or Upgrade Projects.

Context in which the hydrologic/hydraulic impact may be identified as adverse by statutory law	Hydrologic/ Hydraulic Impact	Relevant statutory law	Structural elements to be considered for mitigation, if project is a replacement or an upgrade of existing infrastructure at site
Project crosses regulatory floodway of an NFIP participating community	Increase in water surface elevation for 1% AEP flood	44 CFR 60.3 23 CFR 250 A	Maintain road profile elevation; entrance weir culvert; special steel beam as guard rail; maintain position of bridge piers; sagging of bridge approaches
Project is in a FEMA flood-related erosion-prone area	Increase in water velocity	44 CFR 60.5 23 CFR 250 B	Boxed weir culvert;
Project is near wetlands under the administration of the USDA	Decrease in water surface elevation	Food Security Act	Boxed weir culvert; staggered barrel culvert
Project may cause a diversion or impounding of water, a potential threat to habitats or to real estate	Increase in water surface elevation Decrease in water surface elevation Increase in velocity Change in flowrates	TWC 11.086 TWC 11.152 Any of the other laws listed in this column	Any of the above items in this column
Project has roadside channels crossing driveways, and there is risk of excessive mounding above driveway pipes	Increase in flooding of real estate Ponding on travel lanes or shoulders	TWC 11.086 Texas Tort Claims Act	Sagging designed into new driveways

The community of DHEs and other hydraulics engineers may contribute items to the table, perhaps subject to review by the Hydraulics Branch. The name and contact information of the person contributing the item may be provided in the information to which the item is linked. If placing the tables and linked information on a server accessible statewide is impractical, the tables with linked information may be zipped in a single folder for electronic distribution.

6.8 TRAINING

Training organized by the Design Division would be helpful for each of the items discussed in Sections 6.1 through 6.7. Such training has been explicitly requested for some of the items through the district surveys and interviews. The most frequently expressed need is in relation to selection and usage of hydrologic and hydraulic modeling software. Underlying this need is a need for improving GIS software skills, as this is the basis for competency in using HEC-HMS and other modeling software.

6.9 STATUS OF DHE IN TXDOT DISTRICTS

For an entity to further develop a particular capacity often requires additional personnel, or a change in the status of some of its existing personnel. Not surprisingly, for TxDOT to further develop its capacity to identify and address H&H impacts will likely require a change in the status of its DHEs. As indicated in the survey of state DOTs, the norm appears to be that if hydraulics engineers are in each district, then they are to be full-time. The DHEs are to be full-time rather than part-time, and may need to report to higher levels of management than they do now.

Presently, the nearly exclusive reliance on part-time DHEs leads to H&H issues not always being adequately addressed in particular projects, as discussed in the comparison of survey results in Section 4.2.1, and as shown, for example, in an overreliance on regression equations for hydrologic modeling, as discussed in Section 4.4.2.1. Part-time DHEs are not always able to meet the H&H demands of particular projects, and cannot be expected to meet the additional demands of ensuring training within their particular districts, or even allotting time to receive such training themselves. A full-time DHE in each district is recommended to help ensure that such training occurs throughout TxDOT, as well as to ensure that H&H issues are adequately addressed in particular projects.

Drainage is incidental to the goal of roadway projects. Any entity primarily responsible for roadways may have a natural tendency to underestimate the importance of drainage issues. Yet the proportion of project costs attributable to drainage issues (approximately 40 percent, according to one unpublished “in-house” estimate), the importance of drainage issues to external entities and the general public (as expressed through federal law, state law, the history of case law, and a growing tendency toward the No Adverse Impacts approach and stricter drainage laws), and the importance to TxDOT of not only avoiding lawsuits but also of promoting the welfare of the public, suggest that the full-time DHE report to, or at least have meaningful access to, the highest level of management within each district. As revealed in the district survey, nearly all DHEs report to an intermediate manager. TxDOT should consider not only having a full-time DHE in each district, but also consider the position level of the DHE as it seeks to further define and mitigate adverse hydrologic and hydraulic impacts.

7. SUMMARY

The Texas Department of Transportation seeks to further develop its capacity to identify and mitigate adverse H&H impacts. This goal requires coordination with the local FPA and other external entities, a working definition of adverse impacts based on federal and state laws and other considerations, engineering expertise and software skills for implementing appropriate mitigation measures, and readily accessible documentation for the efficient application of engineering expertise. Training is suggested for defining adverse impacts, coordination with FPAs, conducting site visits, modeling, structural elements of mitigation measures, and documentation. Part-time DHEs, unable to consistently meet all the H&H demands of particular projects, cannot be expected to embrace and promote such training in their districts. Full-time DHEs are required for the training to advance in the long term, as well as to better address the immediate need for more thoroughly addressing the H&H issues of existing projects. Additionally, because of drainage issues being incidental to roadway projects yet broadly important otherwise, TxDOT may wish to consider having full-time DHEs report to higher levels of management.

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WEBSITES

AASHTO Context-Sensitive Solutions, http://environment.transportation.org/environmental_issues/context_sens_sol

AASHTO Center for Environmental Excellence, http://environment.transportation.org

ADH two-dimensional hydraulic modeling software of the U.S. Army Corps of Engineers, https://adh.usace.army.mil/

Digital Elevation Models, soil data, and other GIS data from NRCS, http://datagateway.nrcs.usda.gov

Geopak Drainage Software, www.bentley.com

GSSHA two-dimensional model of the U.S. Army Corps of Engineers, chl.erdc.usace.army.mil/gssha

HEC-HMS for the U.S. Army Corps of Engineers Hydrologic Engineering Center, www.hec.usace.army.mil/software/hec-hms

National Climatic Data Center NEXRAD data, http://www.ncdc.noaa.gov/oa/rsad/mpr.html#data

National Oceanic and Atmospheric Administration Satellite and Information Service NEXRAD data, http://www.ncdc.noaa.gov/nexradinv

TUFLOW Flood and Tide Simulation software, http://www.tuflow.com

United States Geological Survey streamflow and other data, https://waterdata.usgs.gov.nwis/sw, with seamless data at http://seamless.usgs.gov.

APPENDIX A: TEXAS CONSTITUTION, ARTICLE I, SECTION 17

Texas Constitution, Article I, Section Seventeen

Sec. 17. TAKING, DAMAGING, OR DESTROYING PROPERTY FOR PUBLIC USE; SPECIAL PRIVILEGES AND IMMUNITIES; CONTROL OF PRIVILEGES AND FRANCHISES.

(a) No person's property shall be taken, damaged, or destroyed for or applied to public use without adequate compensation being made, unless by the consent of such person, and only if the taking, damage, or destruction is for:

(1) the ownership, use, and enjoyment of the property, notwithstanding an incidental use, by:

(A) the State, a political subdivision of the State, or the public at large; or

(B) an entity granted the power of eminent domain under law; or

(2) the elimination of urban blight on a particular parcel of property.

(b) In this section, "public use" does not include the taking of property under Subsection (a) of this section for transfer to a private entity for the primary purpose of economic development or enhancement of tax revenues.

(c) On or after January 1, 2010, the legislature may enact a general, local, or special law granting the power of eminent domain to an entity only on a two-thirds vote of all the members elected to each house.

(d) When a person's property is taken under Subsection (a) of this section, except for the use of the State, compensation as described by Subsection (a) shall be first made, or secured by a deposit of money; and no irrevocable or uncontrollable grant of special privileges or immunities shall be made; but all privileges and franchises granted by the Legislature, or created under its authority, shall be subject to the control thereof.

(Amended Nov. 3, 2009.)

APPENDIX B: TORT CASES AGAINST TXDOT

In 1999, in Starr County, Lorenzo Villegas was driving on Highway 755 when his car hit a pool of rainwater that had collected on the road. The car skidded and tumbled into a water-filled culvert, where Villegas drowned. The Villegases brought forth a claim that the water on the road was caused by TxDOT's negligence in mowing vegetation and grass along the shoulder and culvert so that the lanes and the culvert could drain properly (Villegas v. Tex. DOT, No. 04-02-00619-CV). The trial court and the appeals court both ruled that the water on the road was an open and obvious condition that an ordinary motorist could have anticipated due to the weather conditions (cite LexisNexis), and that even if the condition could not have been anticipated, TxDOT had no knowledge of an especially hazardous condition at the location. For these reasons, the ruling, filed in August, 2003, was that under the Texas Tort Claims Act TxDOT could not be held liable for the death of Lorenzo Villegas.

In July 1998, in Grayson County, Wendy Duffell and her high school friends were in a car traveling westbound on U.S. Highway 82. As the car rounded a curve it struck several inches of standing water which the driver had no way of foreseeing, hydroplaned out of control, and Duffell was injured. Duffel's mother, Sherry Blain, brought suit on behalf of her minor daughter against TxDOT under the Texas Tort Claims Act (Blain v. Tex. DOT…). She asserted that TxDOT negligently maintained a drain on the inside shoulder of the road at the accident location, causing water to collect and the accident to occur. In the trial court, a TxDOT employee who had been dispatched to the location in response to being informed of the accident testified that there was indeed 7 to 8 in. of standing water in the lane, that he then removed from the drain two or three rake loads of debris and a large plastic bag. After he removed the bag, the ponded water quickly drained. Other TxDOT employees testified that the same drain had clogged several times over the past 15 years or so, and that on four occasions TxDOT had received calls from police advising them of the standing water, though they received no such call on this occasion except for when the accident occurred. The trial court ruled in favor of the plaintiff. TxDOT appealed. The appeals court overruled the trial court, asserting that, because the standing water at the location occurs only on a small fraction of the storms, and that during a storm standing water problems may occur in a variety of locations requiring TxDOT attention, TxDOT could not be shown to have known that the flooding condition would have occurred at that particular location and was not negligent in its attentiveness (or lack thereof) to the potential flooding at the site. The appeals court remanded the case for a new trial.

Other claims brought forth against TxDOT for drainage-related issues under the Texas Tort Claims Act include those of Brenda Fontenot in Orange County (Tex. DOT v. Fontenot, NO. 09-04-038-CV) with the court of appeals ruling in favor of TxDOT in December 2004, and of Kenneth Wardlaw in Kerr County (Wardlaw v. Tex. DOT, No. 04-09-00095-CV), with the court of appeals ruling in favor of TxDOT in November 2009.

APPENDIX C: TXDOT MEMORANDUM: DESIGNATION OF THE DISTRICT HYDRAULICS ENGINEER

Texas Department of Transportation

MEMORANDUM

TO: District Engineers
Phillip E. Russell, P.E.

DATE: January 21, 2005

FROM: Amadeo Saenz, Jr., P.E. AS

SUBJECT: Designation of District Hydraulics Engineer

Issues related to hydraulics/hydrology are increasingly impacting the development of transportation projects and the operations of the highway system. Also, litigation and regulatory issues related to hydraulics/hydrology are involving TxDOT field office staff and are demanding an increased focus.

In order to disseminate information in a more efficient and timely manner, as well as direct specific training to field offices as needed, there is a need to designate a district hydraulics engineer (DHE) as a point of contact for hydraulic/hydrology information.

A list of suggested DHE areas of responsibility is identified in the attachment. Several districts have already designated a DHE. It is requested that the name of these previously designated individuals be confirmed and that those districts that have not designated an individual do so by February 15, 2005. This information should be sent to Mark A. Marek, Director, Design Division.

Once the DHE contacts are established, the Hydraulics Branch of the Design Division will be in contact with these individuals to discuss plans for future support and training.

Attachment
cc: Mark A. Marek, P.E., DES
Thomas R. Bohuslav, P.E., CST
Zane L. Webb, P.E., MNT
Rick Collins, P.E., RTI
William R. Cox, P.E., BRG
Dianna F. Noble, P.E., ENV

District Hydraulics Engineer Responsibilities

- Serve as point of contact for Design Division, Hydraulics Branch for dissemination of statewide policy, guidance, research, training, software and other related hydraulics and hydrologic issues or needs

- Serve as point of contact for district and area office staff for fundamental expertise on hydraulics and hydrology including consistent application of statewide and district design policy

- Serve as the liaison with the Design Division, Hydraulics Branch on complex hydraulics design and hydraulics-related design or policy issues

- Provide design support and approval for hydraulic and hydrologic methods for use by district, area office, and consultant designers

- Oversee and approve or perform routine hydraulic and hydrologic reports, designs, and analyses for district projects and consultant contracts

- Provide hydraulic, hydrologic and related regulatory review of projects prior to preliminary layout or PS&E submission for letting

- Provide mentoring to other district personnel in hydraulics and hydrology and for district staff in hydraulics and hydrology rotation

- Support to the district environmental quality coordinator and/or environmental coordinator on hydraulics for environmental and water quality issues

- Investigate and help resolve drainage-related issues with the public

- Support district maintenance staff with performance and maintenance of drainage structures, including data collection on chronic problem areas or extreme events

- Recommend research and volunteer as research project directors and advisors as approved by the district engineer

- Coordinate with local governments, developers, and property owners concerning hydraulics-related issues, including the monitoring of local studies and activities that may impact TxDOT drainage facilities or operations

APPENDIX D: SURVEY OF TXDOT DISTRICTS

RTI 0 6671 Synthesis Survey: TxDOT Districts SurveyMonkey

1. Does the District Hydraulic Engineer (DHE) or the interim DHE evaluate district projects for negative hydrologic and hydraulic impacts?

	Response Percent	Response Count
Always	21.7%	5
Most times	**34.8%**	**8**
Sometimes	30.4%	7
Rarely	13.0%	3
answered question		**23**
skipped question		**0**

2. At what stage of plan development does the DHE or the interim DHE evaluate district projects for negative hydrologic and hydraulic impacts? Check all that apply.

	Response Percent	Response Count
Planning and Schematic	36.4%	8
Early in PS&E	**77.3%**	**17**
Late in PS&E	45.5%	10
District Plan Review	31.8%	7
answered question		**22**
skipped question		**1**

3. What percentage of the time does the DHE (or interim DHE) perform drainage duties?

	Response Count
	23
answered question	23
skipped question	0

4. Is the DHE (or interim DHE) a Certified Floodplain Manager?

	Response Percent	Response Count
Yes	34.8%	8
No	65.2%	15
answered question		23
skipped question		0

5. Does the DHE (or interim DHE) report directly to the District Engineer, or to an intermediate manager?

	Response Percent	Response Count
Directly	4.3%	1
Intermediate Manager	95.7%	22
answered question		23
skipped question		0

6. How frequently is the DHE or a hydraulic staff member involved in the Planning and Schematic Phase of new projects?

	Response Percent	Response Count
Always	21.7%	5
Most times	26.1%	6
Sometimes	**34.8%**	**8**
Rarely	17.4%	4
	answered question	**23**
	skipped question	**0**

7. Is storm water quality part of the DHE's or interim DHE's duties?

	Response Percent	Response Count
Yes	13.0%	3
No	**87.0%**	**20**
	answered question	**23**
	skipped question	**0**

8. At what point in the design process are the FEMA National Flood Insurance Program [NFIP] floodplains considered? Check all that apply.

	Response Percent	Response Count
Planning and Programming (in which initial investigations are used to generate a rough, planning level cost estimate)	34.8%	8
Preliminary Design (in which the Design Concept Conference occurs, and proposed cross-drainage structures are to be approximately located and approximately sized)	**78.3%**	**18**
Environmental Permitting and Documentation	47.8%	11
Plans, Specifications, and Estimates	73.9%	17
Not at all	4.3%	1
	answered question	**23**
	skipped question	**0**

9. For projects that DO NOT occur within a FEMA zoned floodplain, does coordination take place with the local Floodplain Administrator?

	Response Percent	Response Count
Always	17.4%	4
Most of the time	13.0%	3
Sometimes	21.7%	5
Rarely	**30.4%**	**7**
Not at all	17.4%	4
	answered question	**23**
	skipped question	**0**

10. For projects that DO occur in a FEMA zoned floodplain, does coordination take place with the local floodplain administrator?

	Response Percent	Response Count
Always	**65.2%**	**15**
Most of the time	34.8%	8
Sometimes	0.0%	0
Rarely	0.0%	0
Not at all	0.0%	0
	answered question	**23**
	skipped question	**0**

11. For recent projects, which of the following types involved hydraulic analysis? (Please provide one checkmark for each of the four rows.)

	Often	Sometimes	Rarely	Rating Average	Response Count
A. Pavement overlay	9.1% (2)	18.2% (4)	**72.7% (16)**	3.00	22
B. Culvert Lengthening, less than 10% original length	21.7% (5)	30.4% (7)	**47.8% (11)**	3.00	23
C. Culvert lengthening, greater than 10% original length	**69.6% (16)**	30.4% (7)	0.0% (0)	3.00	23
D. Installation of metal or concrete guard rail at a culvert	8.7% (2)	26.1% (6)	**65.2% (15)**	3.00	23
				answered question	**23**
				skipped question	**0**

12. Complaints are sometimes inevitable even in a perfectly designed project. In the past five (5) years, how many of each of the following complaints (valid or not) associated with drainage has this TxDOT district heard? Note the approximate number for each. Complaints that fall in more than one category should be counted in each category.

	0	1-5	6-10	11-20	more than 20	Rating Average	Response Count
Diversion of a stream or drainageway from its natural or existing path	**68.2% (15)**	31.8% (7)	0.0% (0)	0.0% (0)	0.0% (0)	1.00	22
Backwater from a TxDOT bridge or culvert	**43.5% (10)**	**43.5% (10)**	13.0% (3)	0.0% (0)	0.0% (0)	1.00	23
Increased flooding of property due to TxDOT embankment running parallel to a stream and encroaching upon the stream's floodplain.	**59.1% (13)**	40.9% (9)	0.0% (0)	0.0% (0)	0.0% (0)	1.00	22
Increased flooding due to increased runoff caused by the TxDOT project	**45.5% (10)**	**45.5% (10)**	0.0% (0)	9.1% (2)	0.0% (0)	1.00	22
						Other (please specify)	4
						answered question	**23**
						skipped question	**0**

13. Like complaints, litigation or mediation is sometimes unavoidable. Within the past five (5) years, has the district been involved with hydraulic- or hydrology-related litigation or mediation (for example, alleged flooding, erosion, or unfair taking of property to be used for drainage)?

		Response Percent	Response Count
No		**77.3%**	**17**
If yes, we would appreciate the name of the project with the most serious litigation or mediation. If you prefer not to name the project, simply write NA:		22.7%	5
		answered question	**22**
		skipped question	**1**

14. What references or resources are most helpful to you in estimating and/or avoiding negative hydrologic and hydraulic impacts of TxDOT projects?

	Response Count
	23
answered question	**23**
skipped question	**0**

15. What drainage issues are the most challenging to this District, and for which the District would most likely seek additional assistance or guidance? (You may mark more than one item.)

	Response Percent	Response Count
Acquiring easements for drainage	21.7%	5
Maintenance of drainage	17.4%	4
Diversion of drainage	17.4%	4
Selection and/or use of software	**60.9%**	**14**
Assessing, predicting, or mitigating hydrologic/hydraulic impacts during the design phase	56.5%	13
Temporary drainage/flooding/complaints during construction	17.4%	4
Other (please specify)	26.1%	6
	answered question	**23**
	skipped question	**0**

16. Has this District achieved a noteworthy solution for mitigating hydrologic or hydraulic impacts that you would be willing to share as a helpful case study?

	Response Percent	Response Count
No	86.4%	19
If yes, we would appreciate the project name or a brief description for future reference. If you prefer not to identify the project, simply write NA:	13.6%	3
answered question		22
skipped question		1

17. Do you have any comments or advice you'd like to give other TxDOT Districts or to the TxDOT Design Division in relation to hydrologic/hydraulic issues?

	Response Count
	23
answered question	23
skipped question	0

18. Any other comments?

	Response Count
	11
answered question	11
skipped question	12

Question #12 Open Responses

Complaints are sometimes inevitable even in a perfectly designed project. In the past five (5) years, how many of each of the following complaints (valid or not) associated with drainage has this TxDOT district heard? Note the approximate number for each. Complaints that fall in more than one category should be counted in each category.

Other (please specify)

DHE is not aware of any complaints; However, complaints may have been received and addressed at the Area Office level.

Claim that replacing off-system structure increased capacity created flooding downstream.

Oftentimes property owners will complain to our District about inadequate culvert crossings. As upstream developments occur with limited mitigation (or in some cases, no mitigation), TxDOT culverts do not have the capacity to convey the increased rates.

Complaints are usually received and addressed by the area offices.

Question #14 Open Responses

What references or resources are most helpful to you in estimating and/or avoiding negative hydrologic and hydraulic impacts of TxDOT projects?

In few words, it is the training and having had the opportunity to work with experienced engineers the most helpful.

Hydraulic Manual

We use HEC-RAS and Culvert Analysis

TxDOT Hydraulic Manual FHWA Publications

Hydraulic Design Manual

TxDOT Hydraulic Design Manual

Managing Floodplain Development Manual TxDOT Hydraulic Design Manual

Hydraulic Design Manual; Managing Floodplain Development Through the NFIP training manual site visit, site visit during a major rain event, input from the local maintenance office

TxDOT Hydraulic Manuals. Hydrologic/Hydraulic Training.

Typically most projects are rural, so the process we follow is comparing a Hec-Ras cross section containing proposed and existing water elevations to the elevation of an area of concern. The elevation of an area of concern would be determined by a survey or availabel mapping. This process is fairly basic, so the resources used are the typical resources available in the design manuals. If we have to tackle anything more advanced, we would contact the Division for assistance.

hydraulics manual

Hydro Manual

Hydraulic Manual

appropriate contours

TxDOT Hydraulic Manual

FEMA documentation often prove to be most helpful.

TxDOT Hydraulic Design Manual FEMA Website School Textbooks TxDOT Research Project References HEC-RAS, HEC-HMS, ArcMAP

USGS maps

FEMA, Water Code, HDM, common sense, past experience

In Houston, we utilize various H&H programs to determine drainage impacts resulting from our roadway and bridge improvement projects, and mitigate accordingly. We typically have our designers create an existing drainage model and a proposed model. The two are compared and necessary mitigation volumes are determined. In all cases we attempt to maintain the existing 100-yr water surface profiles of any stream or channel that serves as an outfall for our facility.

Following the Hydraulic Manual, NFIP guidelines, etc. in the design of projects.

Question #15 Open Responses

What drainage issues are the most challenging to this District, and for which the District would most likely seek additional assistance or guidance? (You may mark more than one item.)

Other (please specify)

Detention pond design

Developers changing drainage patterns that impact TxDOT drainage.

tidal areas, storm surge

Design of detention facilities.

The acquirement of licenses for storm sewer modeling programs, such as Stormnet or Stormcad, would be beneficial to our District.

Lack of design experience for many designers, especially for the analysis of FEMA floodplains.

Question #16 Open Responses

Has the District achieved a noteworthy solution for mitigating hydrologic or hydraulic impacts that you would be willing to share as a helpful case study?

If yes, we would appreciate the project name or a brief description for future reference. If you prefer not to identify the project, simply write NA.

Durazno Ponds Girl Scout Channel

For overlays and new pavement Mill and overlay at all FEMA floodplains; maintain existing roadway profile. In Line detention for increase runoff contributed by state ROW to avoid negative impact, use as needed.

Will need to research the most noteworthy and get back with you.

Question #17 Open Responses

Do you have any comments or advice you'd like to give other TxDOT Districts or to the TxDOT Design Division in relation to hydrologic/hydraulic issues?

The Design Division needs to stress the importance of having a DHE in every District. Often this position and what the person does is taken for granted.

We would definitely like to see additional training made available for engineers and designers alike. There appears to be a change in the thought process for calculating flows for various size drainage areas and the old regression equations are somewhat outdated.

availability of HEC-RAS training for designers has been rather limited in recent years

Has there been any additional discussion, or resolution regarding what information, and format of information, should be included in PS&E packages?

Having the DHE under the District Design Engineer seems to work for us. I get involved with drainage at an earlier time. I get to work with Area Offices and Maintenance and Contruction to resolve drainage issues.

Appreciate the interest and inquiries made.

We need an updated Hydraulic Manual, and additional training classes beyond what is currently offered.

Question #18 Open Responses

Any other comments?

A short presentation or guidance document on Texas Water Law provided by the Division would be beneficial during the process of analyzing hydraulic calculation results.

APPENDIX E: SURVEY OF STATE DOTS

TxDOT RTI 0-6671: Synthesis of Hydrologic and Hydraulict Impacts

SurveyMonkey

1. Name of State DOT(Optional):

	Response Count
	35
answered question	35
skipped question	0

2. Name of Person Completing Survey (optional):

	Response Count
	32
answered question	32
skipped question	3

3. Does the DOT have written guidance that distinguishes between acceptable and unacceptable flooding of adjacent property due to a DOT project?

	Response Percent	Response Count
Yes	71.4%	25
No	28.6%	10
If yes, or if informal guidance exists, please describe		29
answered question		35
skipped question		0

4. Does the DOT apply for floodplain permits from the local floodplain administrator?

	Response Percent	Response Count
Always	**28.6%**	**10**
Most Times	25.7%	9
Sometimes	14.3%	5
Rarely	2.9%	1
Never	**28.6%**	**10**
	answered question	**35**
	skipped question	**0**

5. Does the DOT have a procedure for coordinating with the local floodplain administrator?

	Response Percent	Response Count
Yes	**74.3%**	**26**
No	25.7%	9
	If yes, please describe	25
	answered question	**35**
	skipped question	**0**

6. Are No-rise certifications required on DOT projects located within a FEMA floodplain?

	Response Percent	Response Count
Always	14.3%	5
Most Times	11.4%	4
Sometimes	**48.6%**	**17**
Rarely	5.7%	2
Never	20.0%	7
	answered question	**35**
	skipped question	**0**

7. Does the DOT mitigate water surface impacts due to DOT projects to FEMA floodplains?

	Response Percent	Response Count
Always	22.9%	8
Most Times	22.9%	8
sometimes	**31.4%**	**11**
Rarely	11.4%	4
Never	11.4%	4
	answered question	**35**
	skipped question	**0**

8. Does the DOT mitigate the increase in discharge due to DOT projects to FEMA floodplains?

	Response Percent	Response Count
Always	11.4%	4
Most Times	5.7%	2
Sometimes	28.6%	10
Rarely	**34.3%**	**12**
Never	20.0%	7
	answered question	**35**
	skipped question	**0**

9. Does the DOT mitigate loss of floodplain storage due to DOT projects for FEMA floodplains?

	Response Percent	Response Count
Always	8.6%	3
Most Times	2.9%	1
Sometimes	**42.9%**	**15**
Rarely	20.0%	7
Never	25.7%	9
	answered question	**35**
	skipped question	**0**

10. Does the DOT prepare a CLOMR/LOMR when the project reduces water surface elevations?

	Response Percent	Response Count
Almost	5.7%	2
Most Times	2.9%	1
Sometimes	17.1%	6
Rarely	31.4%	11
Never	**42.9%**	**15**
	answered question	**35**
	skipped question	**0**

11. Are No-rise certifications required on DOT projects in areas that are NOT associated with a FEMA floodplain?

	Response Percent	Response Count
Always	2.9%	1
Most Times	5.7%	2
Sometimes	2.9%	1
Rarely	22.9%	8
Never	**65.7%**	**23**
	answered question	**35**
	skipped question	**0**

12. Does the DOT mitigate water surface impacts due to DOT projects in areas that are NOT associated with a FEMA floodplain?

	Response Percent	Response Count
Always	5.7%	2
Most Times	**28.6%**	**10**
Sometimes	**28.6%**	**10**
Rarely	20.0%	7
Never	17.1%	6
Please describe technique(s)		22
answered question		**35**
skipped question		**0**

13. Does the DOT mitigate the increase in discharge due to DOT projects in areas that are NOT associated with a FEMA floodplain?

	Response Percent	Response Count
Always	8.6%	3
Most Times	14.3%	5
Sometimes	22.9%	8
Rarely	22.9%	8
Never	**31.4%**	**11**
Please describe technique(s)		21
answered question		**35**
skipped question		**0**

14. Does the DOT mitigate loss of floodplain storage due to DOT projects in areas that are NOT associated with a FEMA floodplain?

	Response Percent	Response Count
Always	2.9%	1
Most Times	2.9%	1
Sometimes	28.6%	10
Rarely	31.4%	11
Never	**34.3%**	**12**
	Please describe technique(s)	16
	answered question	**35**
	skipped question	**0**

15. Does the DOT have a hydraulic engineering organizational unit?

	Response Percent	Response Count
Yes	**88.6%**	**31**
No	11.4%	4
	answered question	**35**
	skipped question	**0**

16. If answer to #15 is yes, please describe as:

	Response Percent	Response Count
Division	7.1%	2
District	3.6%	1
Section	**67.9%**	**19**
Branch	21.4%	6
Team	7.1%	2
Other (please specify)		10
answered question		**28**
skipped question		**7**

17. Do all districts within the DOT have a hydraulic engineer who is responsible for addressing hydraulic issues?

	Response Percent	Response Count
Yes	37.1%	13
No	**62.9%**	**22**
answered question		**35**
skipped question		**0**

18. If answer to #17 is yes, is hydraulics a full time function?

	Response Percent	Response Count
Yes	**92.3%**	**12**
No	7.7%	1
	answered question	**13**
	skipped question	**22**

19. Does the DOT typically use simple culvert software such as HY-8 to evaluate highway non-bridge class culverts, or does it use more complex software such as HEC-RAS?

	Response Percent	Response Count
Simple (for example, HY-8)	**85.7%**	**30**
Complex (for example, HEC-RAS)	14.3%	5
	answered question	**35**
	skipped question	**0**

20. For highway bridge class culverts, does the DOT use simple or complex software?

	Response Percent	Response Count
Simple (for example, HY-8)	17.1%	6
Complex (for example, HEC-RAS)	**82.9%**	**29**
	answered question	**35**
	skipped question	**0**

21. Has the DOT standardized its use of software so that all its hydraulic engineers use the same software?

	Response Percent	Response Count
Yes	**51.4%**	**18**
No	48.6%	17
If yes, please describe, and discuss the advantages or disadvantages of standardizing the software usage:		19
	answered question	**35**
	skipped question	**0**

22. One of the most challenging obstacles in hydraulic engineering may be assessing how accurately the model (whether the model is, e.g., a simple SCS method equation calculated on paper, or a complex system of equations in software) is predicting the water levels, flow rates or other hydrologic/hydraulic quantities. Does the DOT have any strategies or policies, or do you have any advice for model validation (i.e., for checking that model predictions are reasonably accurate)?

	Response Count
	35
answered question	**35**
skipped question	**0**

23. What reference materials are most useful resources to the central office in formulating design and/or maintenance policies regarding drainage systems of DOT facilities?

	Response Count
	35
answered question	**35**
skipped question	**0**

24. In the last 10 years has the DOT been successfully sued by a plaintiff for an issue related to flooding or drainage?

	Response Percent	Response Count
Yes	37.1%	13
No	**62.9%**	**22**
If yes, please explain what happened and how it might have been avoided:		19
	answered question	**35**
	skipped question	**0**

25. In cases of inverse condemnation brought by property owners against the DOT for alleged flooding or other alleged adverse hydrologic/hydraulic impacts, how often does the DOT claim sovereign immunity to SUCCESSFULLY defend itself?

	Response Percent	Response Count
Always	0.0%	0
Most times	11.4%	4
Sometimes	0.0%	0
Rarely	2.9%	1
Never	22.9%	8
No inverse condemnation claims have been brought against the DOT for adverse hydrologic/hydraulic impacts.	5.7%	2
I don't know	**57.1%**	**20**
	answered question	**35**
	skipped question	**0**

26. Any comments or suggestions?	
	Response Count
	15
answered question	15
skipped question	20

Question #3 Open Responses

Does the DOT have written guidance that distinguishes between acceptable and unacceptable flooding of adjacent property due to a DOT project?

If yes, or if informal guidance exists, please describe

Typically limit backwater to less than 0.5 ft. Consider land use of impacted property.

Provide one foot minimum 'freeboard' from developed property (building) or roadway whichever is lower. Additionally, do not worsen existing flooding condition if it cannot be practically eliminated by proposed project."

The xDOT Drainage Manual http://www.dot.state.x.us/bridge/hydraulics/drainagemanual/index.html has general statements about flooding adjacent properties in sections 4.2.1 5.2.1 5.2.2 5.2.3 8.2.1 and Appendix A

xDOT general strategy for managing project-related flooding impacts is presented below 1. Avoid all project-induced adverse flooding impacts on properties adjacent to the project locations to the maximium extent practicable. 2. If adverse project-indiced flood impacts on adjacent properties cannot be reasonably avoided- then xDOT will negotiate reasonable flowage easements or permanent ROW takings with the owners of the affected properties.

Informal guidance suggests no flooding to any insurable structures during passage of 100-year flood due to highway improvements, and/or no net increase in flood depths if structure is already subject to flooding during 100-year flood.

Formal or written guidance is as follows…

As per state law (administrative code) it is not permissible to increase the probability of flooding properties located upstream from any stream crossing. In urban areas, storm drains on new construction are designed to avoid flooding of structures up to a 100-year storm event.

Use state and federal regulations

CFR 650

100 year frequency used to limit increases in flooding of adjacent property. If property is already subject to flooding then design may be used to eliminate it if practicable or reduce it.

Please see the following link for our general drainage policies and practices, http://www.xdot.org/doh/preconstruct/highway/hydro/gl0399web/ii.html

Sate Drainage Manual states that backwater must be kept to 1.0 ft or less above natural condition. If flooding of structures is already occurring, backwater should not be increased.

As per our current state regulations as set forth by DNREC (Division of Natural Resources and Environmental Control) water quantity has to be mitigated as per peak flow for the 2 and 10 yr storm events below the C&D Canal and the 2, 10, and 100 yr storm events above the C&D Canal with post-developed matching pre-developed. There is a waiver if your post-developed 2yr event is not greater than 10 percent over the 2yr pre-developed and/or as well as if you can prove safe conveyance to tidal waters. We also try to be careful in looking at downstream effects in as far as using "engineering judgment". When the new regs are enacted this coming January, the whole state will be required to start doing more of a volume based management approach for the 2, 10, and 100 yr storm events.

Design Division Drainage Manual outlines small culvert and storm drain design and Structures Division Design Procedures for Hydraulic Structures outlines design practices for bridges and large culverts. Both are on the xDOT website.

See 10.6.6 Risk Evaluation in Drainage MOI; any increase in flooding potential as a result of a project will trigger additional ROW and/or drainage easements.

The backwater created by the culvert at design storm condition should not increase flooding of adjacent property.

Acceptable for temporary: less than the FEMA 1.0 ft. rise (or less if noted in FIS), and no insurable properties upstream. Permanent structures strive for no WSEL increase

If an increase in backwater goes outside of our ROW, we are required to certify the increase is "non-harmful" and send affected property owner statements to anyone impacted by the increase.

Design Manual 2 Chapter 10 contains information regarding acceptable increases and how to compare models to FEMA models.

The guidance is contained within the design guidelines. For example :... flow conditions shall be analyzed for the 100-year event. Mitigation must be provided if the 100-year flow conditions within or outside of xDOT right-of-way are unreasonably aggravated.

Guidance somewhat dependent on scope of potential damages. Stated policy: avoid damages like this where practical. Designer should develop and consider alternatives that minimize or ideally if practical eliminate damages. If damages caused, documentation must be present justifying choice of "undesirable" option. That scenario is very uncommon.

100 year elevation is 2 ft below a house

If we are going to increase flooding on adjacent property, we will buy a drainage easement.

0.10 ft. maximum increase for improved properties and up to 0.5 ft. on unimproved properties.

xDOT abides by the xDES Stream Crossing Rules and substantially complies with the Alterations of Terrain Rules (AOT). Flooding above the BFE is not allowed, hydraulic modelling is more common. Additional guidance is under review in the form of an updated xDOT Drainage Manual.
http://des.x.gov/organization/divisions/water/wetlands/streams_crossings.htm
http://des.x.gov/organization/divisions/water/aot/index.htm

xDOT Bridge Design Manual and xDOT Road Design Manual, Drainage and Culvert Design. xDOT follows state statutes, rules and regulations.

In a FEMA Zone AE the 100-year flood elevation impact is limited to 0.0' In a FEMA Zone A or undeveloped area Max flood elevation impact is 1.0' unless there is existing development upstream then the elevation impacts are limited to 0.0.

All bridges/culverts will be designed to minimize upstream flood elevations for the 100 year flood that will impact high damage potential properties.

I am not aware of any DOT&PF efforts to define "acceptable flooding" versus "unacceptable flooding". Flood risks are evaluated on a project-by-project basis. The ADOT&PF Drainage Manual is modeled after the AASHTO Model Drainage Manual. Federal Regulations also cover flood plain evaluations, such as 44 CFR 60, 23 CFR 650. FEMA and NFIP communities define "unacceptable" in terms of quantitative impacts to the regulatory floodway, which ADOT&PF must evaluate. AASHTO Drainage Guidelines list general hydraulic design objectives for projects, against which "acceptability" may be assessed.

x State Law

Question #5 Open Responses

Does the DOT have a procedure for coordinating with the local floodplain administrator?

If yes, please describe

(NOTE: HIGHLIGHTED RESPONSES ARE OF DOTs WHICH NEVER APPLY FOR PERMITS FROM THE LOCAL FPA, BUT WHO HAVE A PROCEDURE FOR COORDINATING WITH THE LOCAL FPA.)

Notify local floodplain administrators of any activities in zoned floodplain

If a regulated floodway is involved, we submit our floodway analysis via post office.

Some require more coordination than others. Generally, we like to call them during the project development to make sure that we're using the correct mapping and to give them a heads up on major projects. We have also had good success on meeting with them out in the field for complex projects.

Write letters providing the proposed changes to the flood conditions

xDOT Hydraulics Unit coordinates with the x Floodplain Mapping program (FMP), the delegated state agency for administering FEMA's National Flood Insurance Program, to determine the status of the project with regard to applicability of xDOT'S Memorandum of Agreement with FMP, or approval of a Conditional Letter of Map Revision (CLOMR) and subsequent final Letter of Map Revision (LOMR). Please see the following link for our memorandum of Agreement with the x FMP
http://www.xdot.org/doh/preconstruct/highway/hydro/FEMA/default.html

If no-rise, technical data is sent to community for review and a letter of concurrence with project is requested. If CLOMR is needed, technical data is sent to community and required information is sent to FEMA. If consultant project, consultant does coordination.

The State Department of Environmental Protection (DEP) is the "local floodplain administrator" for State funded/administered projects. xDOT has regular pre-permit application and screening meetings with the DEP and other regulatory agencies such as the ACOE for coordinating the required permits and Flood Management Certifications for projects.

Done during project planning. Coordinated by the Office of Environmental Services.
http://www.dot.state.x.us/environment/

xDOT coordinates directly with FEMA Region 1 if a project's implementation will necessitate revisions to National Flood Insurance Program base (100-year) flood mapping products.

We do not have any local floodplain administrators.

No rise certifications are sent to the local government on all crossings with streams that have detailed fema studies or a complete map revision package including forms and RAS model results is sent for signature and forwarded to FEMA if a 0.00 ft rise cannot be achieved at the crossing.

Coordinates with Comprehensive Emergency Management 1110 State Office Building x City, x xx114

During environmental consultation for 404 permit with the Corps of Engineers

We have a Memorandum of Understanding with our DEQ that outlines coordination between the two agencies.

Our main regulatory agency regarding project impacting floodplains is Dept of Env Protection which issues Water Obstructions and Encroachment permits. Design Manual 2 Chapter 10 describes xDOT coordination with FEMA and local municipalities who are responsible for floodplain management. Note: We do not have anything specifically called a "No rise certificate."

The local floodplain coordinators are contacted at the initiation of the project, and consulted for their knowledge of the project, and for recommendations.

xNR has formal application for major rivers, sensitive or public body sites, along with statewide program allowing agencies to self-permit if meeting certain criteria. Formal and statewide permit processes described in xDOT Drainage Manual. Update out in July 2011.
Letters are sent to the local FPM for projects in the floodplain.

Hydrology and hydraulics reports submitted for review and approval prior to submitting JPA
Approximately 30 days before project is let to contract, we send plans and a sample letter to local floodplain administrator with a letter certifying project compliance with local ordinance, and request approval letter or floodplain development permit.
The Hydraulics Section coordinates with the Floodplain Management Coordinator: Floodplain Management Coordinator x Office of Energy and Planning 4 Chenell Drive, 2nd Floor, x, x 03301 Main - x-271-2155 | Direct - x-271-1762 Fax - x-271-2615 | www.x.gov/oep

xDOT adheres to FEMA (NFIP) regulations which are enforced through the x Dept. of Agriculture, Division of Water Resources. xDOT contacts local FP administrators for CLOMRs, floodways typically.

The State Level FPM requests that we provide the local FPM with the results of our analyses for their information. This is likely to be done on an inconsistent basis.

Record of Coordination to show the local governmental agencies that our project will not violate their flood plain management ordinance.

Generally, our regional environmental staff coordinate with the staff of NFIP participating communities for flood hazard permits. Regional or statewide hydraulics staff (or consultants) provide the technical review and certifications, as required. RE: Q4. DOT&PF applies for floodplain permits when working within NFIP participating communities.

Question #12 Open Responses

Does the DOT mitigate water surface impacts due to DOT projects in areas that are NOT associated with a FEMA floodplain?

Please describe technique(s)

We design most drainages not to increase the water surface elevation for major drainages. For minor drainage the water surface may be increased if there is no developed property subject to inundation.

Generally if there is a increase in the water surface elevation of a stream or floodplain area the effects are evaluated to determine the significance of the impact. If buildings are involved general practice is to design not increase or cause flooding of the structure.

Backwater is kept to 1.0 ft or less above natural condition.

Purchase flooding rights or easements

xDOT general strategy for managing project-related flooding impacts is presented below 1. Avoid all project-induced adverse flooding impacts on properties adjacent to the project locations to the maximum extent practicable. 2. If adverse project-indiced flood impacts on adjacent properties cannot be reasonably avoided- then xDOT will negotiate reasonable flowage easements or permanent ROW takings with the owners of the affected properties.
Our mitigation comes as a result of a couple of lawsuits that we have had over the years.

Basically, xDOT got sued/blamed for residents having to buy flood insurance when the floodplains were "recalculated" after we had already built some major projects. We do not have any "set" rules at this time. Again, we try to use engineering judgment in looking at potential floodplain impacts and hence will do more detailed analysis if we feel that there might possibly be an impact. If an impact is predicted, than we try and mitigate as best as possible.

Generally don't allow more than 1.0 of rise on any structure over 1000 acres.

In some cases, excavation on the floodplain or under the bridge in overbank areas, leaving sediment ponds in as permanent detention ponds, check dams in ditches, oversizing the storm drain system to detain water, and/or internal and external energy dissipaters have been used to mitigate flow or velocity impacts to sensitive areas or streams.

drainage easements

By designating or acquiring easements.

This would be done through temporary or permanent flowage easements obtained from property owners impacted by the project.

If there are potential impacts to adjacent property owners, the water surface impacts will be mitigated. If the downstream conveyance is adequate, or the property owner an agency, then the additional WSE may not require mitigation. It's definitely case-by-case.

Steps are taken to mitigate impact through design features (excavation under bridge, berms, etc.) and flood easements.

meet local floodplain administrator request

Purchase of flood easements

Try to determine if adjacent structures are subject to flooding during design flood or 100-year flood. If so, we design new drainage structures and roadway embankment to cause no increase.

SCS based modelling such as the proprietary HydroCAD software is often performed for design purposes. HEC RAS models are also used for determining water surfaces.

The x DOT has a general criteria that there shall be no increase in runoff due to a proposed improvements. All additional runoff shall be retained onsite.

xDOT uses "reasonable use" policy for areas not mapped. This is usually a 1 ft. allowable rise unless insurable buildings may be affected - then typically don't allow for worse conditions.

If 100-year flood impacts exceed 1.0' then impacted property owners may be compensated and possible flood easements purchased

Maintaining road grade overtopping elevation, making bridge larger, buying flowage easements.

General practice is to avoid or minimize surface water impacts to the extent practicable. Other (non-FEMA) regulations, permit stipulations, environmental commitments, and so on address surface water impacts. (RE: Q8/9/12/13/14. Mitigation would be commensurate to risks and may be dictated by regulatory permit. Q10. NFIP communities are responsible for the CLOMR/LOMR coordination. DOT&PF can provide documentation or may do more, upon request. Q11. No-rise certifications are not required by the State of x in Non-NFIP areas, but A.O. 175 directs the DOT&PF to use 44 CFR 60 as a guide.)

Question #13 Open Responses

Does the DOT mitigate the increase in discharge due to DOT projects in areas that are NOT associated with a FEMA floodplain?

Please describe technique(s)

ditch storage, detention ponds

drainage outfalls are evaluated for significance of impact. Some techniques: Improvement of existing drainage outlets to accommodate increased flow to a point where the impact is no longer consider detrimental. Providing storage areas along the project to reduce impact. Detention Basins. Energy dissipaters.

Detention basins

Some watershed districts require infiltration or volume reduction.

See response to Item 3.

See answer to #12.

Measures as above would be used.

channel improvements

By designating or acquiring easements.

Our mitigation is based on water surface elevations, not discharge

As necessary depending on the adjacent property ownership and conveyance as noted in question #12. Case-by-case.

meet local floodplain administrator request

Purchase of flood easements

Increase in peak discharge is not allowed. Design techniques for attenuation are often used. Increased volume of discharge is sometimes designed for.

Generally requires assessment of increased erosion potential and associated need for energy dissipation or bank protection.

Same response as #12.

Not clear on this question, we follow state SWM Regulations for water quality and quantity management but these requirements vary and do not extend to the 100-year discharge

Purchase of flowage easements.

Mitigation would be commensurate to the risk and may be dictated by regulatory permit. Detention/retention objectives (or requirements) are becoming common.

Detention ponds

Question #14 Open Responses

Does the DOT mitigate loss of floodplain storage due to DOT projects in areas that are NOT associated with a FEMA floodplain?

Please describe technique(s)

The loss of flood plain storage at a highway crossing is typically insignificant effect on peak discharge such that methods to estimate effect on peak are not conclusive as the analysis does not escape the noise level. For example, an analysis of the effects of longitudinal encroachment on flood plain storage showed the peak was DECREASED due to "loss of storage". The encroachment increased the stage such that the computed discharge "DECREASED" due to the storage provided at the deeper depth.

Removal of old roadway fill or excavation of natural ground.

For significant storage loss, hydraulic analysis will include flood routing to determine downstream effects of storage loss.

Under the terms of the x Wetlands Protection Act, xDOT is obliged to provide incremental volumes of compensatory flood storage for all natural flood storage volume displaced by project activities, regardless of the projects location relative to mapped NFIP Special Flood Hazard Areas.

See answer to #12.

TVA and USACE reservoirs require fill offset plans if fill is being placed in the flood storage zone, power storage zone, or flowage easement. Often these reservoirs also have fema floodways defined on them. In some cases longitudinal encroachments have required the steepening of slopes and gaurdrail, retaining walls, and/or equalization pipes to maintain floodplain connection to the other side of the road.

such losses are rarely significant for representative reaches

By designating or acquiring easements.

As necessary depending on the adjacent property ownership and conveyance as noted in question #12. Case-by-case.

meet local floodplain administrator request

Purchase of flood easements

This situation is reviewed as part of the wetland permitting path.

n/a

Reduction of floodplain storage due to highway activities is very rare. Stream velocities and water elevations are evaluated for site conditions and a policy of "reasonable use" is followed in unmapped areas which typically limits elevations to 1 ft. or less.

We evaluate projects based on the hydraulic impacts of our projects. These may include lateral encroachment into a flood plain by a project. This would be included in the hydraulic analysis for the overall impact. This is not done from a hydrologic perspective.

Mitigation would be commensurate to the risk and may be dictated by regulatory permit. Detention/retention objectives (or requirements) are becoming common.

Question #21 Open Responses

Has the DOT standardized its use of software so that all its hydraulic engineers use the same software?

If yes, please describe, and discuss the advantages or disadvantages of standardizing the software usage

We try to use the software developed or recommended by the FHWA such as HY8, Hec Ras, WMS. The advantage of using this software is that its a no cost, we can comment on bugs, and we can receive training through NHI.

We use various software for Bridges HEC-RAS, WSPRO, HDS-1 WSPRO and HDS-1 are the best for bridges. HER-RAS implementation of WSRPO is poor. We use flood routing in culvert design using CDS to estimate effects of storage created by the embankment.

HECRAS is the standard for bridge structures and bridge size culverts. Two dimensional models are rarely used but can be if the benefit is worth it. Smaller culverts are more flexible in the design software. Advantages, Familiarity, consistency. Disadvantages: flexibility to use different models where appropriate.

Not standardized but have a short list that engineers choose from based on situation, personal skill and experience.

Provides for efficient inter-section data exchange. Guarantees reproducibility of analysis performed by any section staff member. Economical to update software on a section-wide basis.

Hydraulics Section is located in one section at HQ with 8 to 9 engineers for the entire state. Standardization is a must for group continuity and in dealing with consultants designing structures for various local programs.

Generally yes. We use HEC-RAS for all bridge sized structures, and recommend it for larger culverts (span > 12 ft). All other culverts use HY-8. Hydraulic engineers have available WMS; some use it, some don't. For hydrology on larger basins we use USGS StreamStats NY edition. Small drainage basin hydrology use TR-55, or rational method.

There are so many computer program options out there, it would be impossible to be "expert" in all of them. We limit what software is available so that we maintain institutional expertise.

Advantages include: ensure that all staff have updated versions; ensure that all new versions are thoroughly tested; ensure that our numerous consultants are designing bridges and culverts in a similar fashion, makes QA of H&H reports much easier.

Decreases software costs, increases consistency, and increases proficiency.

NO, but we are focused on public domain from FHWA and Corps\HEC.

Staff develops good knowledge of software applications.

Although the answer to this question is No, I believe that clarification is needed: Routine highway drainage calcs. are "typically" performed by Final Design Teams in NH. HEC RAS is often used by the Hydraulics Section for non-bridge/culvert evaluation, especially if there are multiple culverts in series. xDOT has a Bureau of Environment within the Dept. that typically performs Stream Crossing Assessments. The Hydraulic Section is currently working on standardizing.

For small culvert / bridge crossings, HY-8 is utilized. HDOT uses HEC-RAS for more complex bridge crossings.

KDOT uses WinHY8 for culvert crossings and HEC-RAS for bridges and complex culverts sites. No disadvantages. Training for staff is more uniform, all consultants use the same, HEC-RAS is widely accepted and has scour and channel design modules.

We find it provides a consistent product and also provides a consiseant process for us to receive and review designs from the consultant community. They don't have to use different software for different districts.

Utilize HEC-RAS for bridge and internal program for culvert hydraulic analysis. Starting to use 2-D modeling for complex locations since x has LiDAR elevations for the entire State.

RE: Q19, use of HEC-RAS is becoming more common for culvert analysis. (The question should have allowed for "both" as an answer option.)

Question #22 Open Responses

One of the most challenging obstacles in hydraulic engineering may be assessing how accurately the model (whether the model is, e.g., a simple SCS method equation calculated on paper, or a complex system of equations in software) is predicting the water levels, flow rates or other hydrologic/hydraulic quantities. Does the DOT have any strategies or policies, or do you have any advice for model validation (i.e., for checking that model predictions are reasonably accurate)?

Collect high water marks, historic flooding observations and scour observations

Attempt to calibrate model as much as possible using historical data/anecdotal information, rainfall data, stream gages, etc.

Use HEC-RAS reference manuals for hydraulic modeling validation.

Generally, we evaluate how the existing structure is performing by talking to our maintenance folks to see if the have been any problems in the past, did the roadway overtop, or have there been any significant events that they remember. This information is then used in calibrating the existing model by trying to reproduce what we were told. Also, surveying the high water marks also help in the calibration. If the site is gaged we can survey the water surface elevation and match it to flow rate for that day. Although this is rare.

model validation is rarely done due to lack of data to calibrate and time to perform a validation. It is very difficult to validate hydrology models that are rainfall based

Validate the results with gage data, FEMA data and field investigation.

Historical information (property owners, local officials, maintenance personnel, gage records for larger structures) for calibration of models. Similar for smaller crossings site evidence of recent high water, etc.

For validation of floodstage elevations, best way is comparison with USGS gage data if available at site. Also, check recorded highwater elevations at site or any other available historical data, including bridge maintenance records.

There is some guidance in the x Drainage Manual regarding model calibration in the Hydrology chapter. Hydraulic models are reviewed for reasonableness with known flooding conditions and history if available.
http://www.x.gov/dot/cwp/view.asp?a=3200&q=260116&dotPNavCtr=|#40139

Try to get a high water mark elevation from surveys, also check with District on historic performance of existing structure. May calculate hydrology using multiple methods and select the one that matches field or historical data best.

To ensure regulatory compliance of most xDOT projects crossing non-tidal riverine waterways, hydraulic models generated by xDOT Hydraulic Section are calibrated against published NFIP base flood profile data. For many bridges crossing tidal waterways, hydraulic models are calibrated against tide stage elevation data acquired in proximity to the project location by means of continuously monitoring temperature depth recorders (TDR).

We do not have a policy, but the only strategy I'm aware of at the moment that we would potentially use is to calibrate any model in relation to the regression equations.

We run existing models that must be calibrated with records and information from past storms

The section routinely checks USGS, USACE, TVA and FEMA studies, data, and reports as well as compare to survey data on high water marks and local residents testimony and field conditions observed at the structure during the design process to determine if the model results are realistic or not.

model existing bridge etc. for known flood event and compare with known flood elevations etc.

HEC-RAS we assume reasonably accurate so long as field survey x-secs are good. Each bridge project calcs are independently checked for hydrology and hydraulics. Sometimes run an independent HY-8 for a large culvert just to check. Hydrology we've found that TR-55 can sometimes be way off. We recommend that the designer take a look also at rational and USGS StreamStats (even if less than minimum recommended drainage area) to see if values are at least reasonable.

We are not developing regulatory floodplains at the DOT. We look at the models as a comparison between existing and proposed but base them on available FIS information where available.

We have a consultant who tests all new releases of software before approval for use on xDOT projects.

This remains one of our more challenging tasks. If the calculations are too conservative, and you decide not to use them, then you are increasing the DOT liability. Model calibration is being used by local agencies, but there are issues with the calibration process.

Not really. Effort is made to validate models with historical flood observations- depth of flow, rainfall, gage data, etc. But we don't calibrate the models, per se, or use physical models to test numerical.

compare with fema flood profiles or Corps of Engineers models

Using gage data or surveyed highwater marks whenever possible; always testing the model's length for TW stability at structures.

Try to compare to observed high water information if it is available, but it is often unavailable for smaller streams.

As with any form of calculation verification by a second method is good practice. For example one may use a deterministic method and compare with a Stochiastic equation, or one may compare water surfaces determined with HY8 vs. HEC RAS for sensitivity to parameter adjustments. Field observations and anecdotal evidence may be useful. Actual gage measurements for verification are preferred but the pacity of data usually makes other engineering judgment necessary.

In addition to the calculated results, the engineer must use engineering judgment by: using other software methods such as TR-55 or Rational to comparison purposes; field observations, maintenance reports of past history at the site; previous hydrological reports prepared by others.

We always check/verify water surface elevations with survey, high water marks, inspection reports and landowner accounts whenever available.

We use the best information available. We have worked with the USGS to establish regional regression equations based on a network of gages. We attempt to use historical flood data when it is available to validate the hydraulic models.

Short of calibrating the rating curve for a known flood elevation and discharge using a USGS gage or USGS flood report, there is no way to check models.

Use multiple methods. Consider channel geomorphic properties during hydrological studies. Calibrate models to known water surface elevations/flow rates.

Question #23 Open Responses

What reference materials are most useful resources to the central office in formulating design and/or maintenance policies regarding drainage systems of DOT facilities?

xDOT Facilities Development Manual, xDOT Bridge Manual and various FHWA publications

USDA Urban Hydrology for small watersheds (TR-55), NRCS Hydrology Manual for x, AASHTO Highway Drainage Guidelines, HEC 14, HEC 18, HEC 22

FHWA publications

Roadway Design Manual All HEC manuals

AASHTO model drainage manual, AASHTO Drainage Guidelines, Past Experience, FHWA HEC series

publication and software from FHWA

Experienced engineers, FHWA, Universities research,

HEC 18, 20,21,23 & 25, USGS publications, AASHTO Drainage Manual, Drainage manuals of other states

x DOT Drainage Manual, FHWA Hydraulic Engineering, Circulars/Design Series, AASHTO Drainage Manual

FHWA HEC manuals, AASHTO manuals, research results.

x GIS database

Road designers use our xDOT Roadside Design Manual, Chapter 6 in as far as a design standard for drainage (basically based on HEC 22). Bridge designers use the xDOT Bridge Design Manual.

we use flood information sheets and bridge inspection reports

Model Drainage Manual x DOT Drainage Manual

Inspection and Repair Section of Structures Division and the Maintenance Division handle each situation individually in formulating the repairs or maintenance needed on all size structures.

FHWA HEC & RD & HRT & TS Manuals, AASHTO Model Drainage Manual

Federal manuals

FHWA manuals: HEC 18, HEC 23, etc. The AASHTO Model Drainage Manual as modified for xDOT>

A drainage manual is an immense help and provides consistency.

HEC and other widely accepted manuals are used in developing xDOT Manuals

FHWA Publications and DOT manuals are used the most often. AASHTO publications are used on occasion.

FHWA HEC and HDS publications

research

xDOH Drainage Manual xDOH Maintenance Manual

Federal and state regulations, FHWA and NCHRP publications, research reports.

State DOT Drainage Manual, AASHTO Drainage Manual and Drainage Guidelines

xDOT Highway Design Manual, Drainage Manual, Construction Manual, Policy Manual for the Permitting of Driveway and other Accesses to the State Highway System, ASSHTO Manuals, FHWA Resource Center, and policy memos to name a few.

FHWA HDS & HEC publications and NCHRP research studies.

HEC Manuals and other technical circulars published by FHWA.

xDOT Design Manuals. AASHTO policies, FHWA documents (HDS, HEC, others).

Drainage Design Policy is constantly being adjusted due to environmental practices and policies imposed by state and federal agencies. With regard to large rivers and streams we do acquire the FEMA hydraulic models, when available, and use the published FEMA discharges (if they appear reasonable) in developong our models for assessing the potential impact due to our projects.

AASHTO Guidelines

FHWA and AASHTO publications, generally. Also, TRB/NCHRP, USACE, USACE-CRREL, USGS, and DOTs(nationwide)-sponsored publications on hydrology, hydraulics, drainage, and cold region issues. Other agencies texts, to a lesser degree: NRCS, USDA-FS, USF&WS, NOAA-NMFS, NOAA-NWS, BLM, and so on.

xDOT Drainage Design Manual and Federal Publications

Question #24 Open Responses

In the last 10 years has the DOT been successfully sued by a plaintiff for an issue related to flooding or drainage?

Typically would involve diversion of water or extreme increase of flow. Better evaluation of how the project would impact the property and taking proactive measures to mitigate for it. Being aware of effects of raising roadway grade or making other changes to the roadway geometry that would impact different flooding events etc.

A hydraulic study was completed in a district office to size a bridge. After the bridge was constructed, a house and other buildings on property sustained flood damage. DOT hired a consultant to do another study. Errors were found in the original study. It was determined by USGS that the event in excess of 100 year storm. House and buildings are located within the limits of the 100 year floodplain. As a result of lawsuit, new bridge was lengthened and lawsuit was settled. At the time the original study was completed, district offices performed studies occasionally. Prior to the above flood event all hydraulic studies were centralized within bridge office hydraulic group. This was done since the engineers in the district offices do not perform studies on a regular basis and needed retraining each time. Also, a review policy was begun as well at this time.

I do not believe xDOT was actually sued, but we have been contacted by lawyers in the past claiming that xDOT was responsible for private home owners having to purchase flood insurance (that didn't need it before) as well as an inverse condemnation. Upon those claims, xDOT had to expend quite a bit of resources researching and doing a flood study to provide the most accurate information possible. After the information was provided, I never had any follow up to hear of the final outcome. As for potential future avoidance, I believe that during the design process, everyone needs to be aware that at any time in the future, you could be contacted for a flooding issue and hence all the calculations and risk assessments need to be well documented and defendable with sound engineering practices.

Nuisance claims and inverse condemnation claims are filed each year regarding drainage issues with varying amounts of success. Most are on smaller structures instead of the large bridges so more diligent design practices can avoid most of these claims.

policy was not followed; remedy was/is to follow policy

There is no way to avoid this, other than a jury of engineers. The DOT was in the right, and the jury awarded 1/2 of the developers claim amount. Typically, when the jury takes the claim amount and cuts it in half, they are undecided, or they do not fully understand what the issues are. This is the case here. The plaintiff pushed for jury, as he knew they would not understand the issues, and he would be awarded 1/2 of his asking price. This is a big problem in my opinion.

each case has parts that are special to that case. from survey not correct to water being diverted that was unknown. over all 400 drainage projects a year less than 4 projects a year with a problem.

the check storm (overtopping flow) was ignored for culvert design in the 1960's

DOT removed a culvert crossing and redirected runoff to an adjacent crossing. Downstream property owner sued claiming increase in runoff across a portion of his property (although he owned property downstream from both sites). Should always make it a goal to maintain existing drainage patterns/paths.

Although the answer is yes, it has been more common that the DOT has successfully defended against litigation. There have been several cases in the last 3 years and each one is complicated typically involving the Attorney General’s Office and several reports by both sides. Westlaw has a citation from a recent case Henkel v. x. Often times Plaintiff action involves multiple parties such as two States or Municipalities and the State. Funds could be better allocated to actual resolution of the underlying drainage problems in an ideal world. It is unlikely that all litigation can be avoided and it is not apparent how the litigation of recent years could have been avoided.

Instances are too numerous to cover in this space. Most lawsuits are based on inverse condemnation.

Do not wish to explain.

APPENDIX F: COMPREHENSIVE LIST OF QUESTIONS FOR PERSONAL INTERVIEWS WITH TXDOT DISTRICT HYDRAULIC ENGINEERS

Hydrologic and Hydraulic Equations/Models

For bridge or bridge-class culvert (that is, large project)…

- What is used for rainfall data?
- What is used for hydrologic modeling? (regression equations, NRCS, HEC-HMS, …)
- What rules of thumb or strategies do you use to test the reasonableness of the hydrologic estimates?
- What is used for hydraulic modeling? (HEC-RAS, …)What rules of thumb or strategies do you use to test the reasonableness of the hydraulic estimates?

For smaller culverts (that is, for land areas of less than 200 acres or so)…

- (repeat above questions)

Documentation/Meetings/Correspondence/Site Visits in Design Phase

- Do you meet with agencies, authorities, property owners, and if so, who and when?
- Where are sign-in sheets and meeting notes kept?
- Where are e-mails, MOUs, and written correspondence kept?
- Is there a hydraulic report? If so, what of the above is kept in it?
- Any stored electronically – if so, what and where?
- Is H&H design engineer/review engineer able to visit site, see images of it, see survey? Is this adequate?
- Is much hydraulic report info kept on design drawings, even if contractor will never use it – but for future convenience of engineering staff?

Design Technologies – which of the following used in the district, why, and how modeled

- Open channels, lined, types of flexible and rigid lining – modeled? Software used?
- Open channels, vegetated – modeled? Software used?
- Storm sewer, IF SO, equations, software used?
- Detention/Retention facilities
- Pumping stations
- Other?

Other Design Issues

- Issues regarding easement acquisition?
- Risk assessment/selection of design flood/check flood?
- Philosophy, ideas, lessons learned regarding design?
- When are consultants used?

Construction

- Any drainage-related complaints during construction? Describe

Are complaints documented? Water levels documented? How, and where kept, electronic storage/accessibility?

Any lawsuits due to drainage-related problems during construction?

Who designs/reviews SWP3?

Sign-in sheets for pre-bid and construction progress meetings – where kept, electronic storage/accessibility?

Change orders? Where kept, electronic storage/accessibility?

As-builts? Where kept, electronic storage/accessibility?

Philosophy, ideas, lessons learned regarding construction?

Operation and Maintenance

What are the most important drainage-related maintenance issues?

In regard to drainage-related issues, which ones consume the most time for maintenance crews?

Who schedules maintenance crews, and on what basis?

How do maintenance crews document their work, and where kept? Electronic storage/accessibility?

Complaints after construction? Common types, how documented, where kept, storage/accessibility?

Lawsuits for drainage-related issues allegedly occurring after construction?

APPENDIX G: QUESTIONS FOR MAINTENANCE AND LOCAL PERSONNEL

Questions for Maintenance Supervisors (typically about one per county) or other Local Personnel
District:__________ Office:__________ Person/Role:_______ Contact Info:____________

My name is John Joseph, with the University of Texas at San Antonio. We've been hired by TxDOT for Research Project 0-6671, which has to do with drainage-related issues. (Describe more, if desired.) We are hoping you have time to share what you see as the most important issues, how the maintenance department works, and any insights you have.

What complaints do you often hear in relation to drainage?

Of all the tasks your crews have to do in relation to drainage (cleaning out culverts, putting out signs for road closures, repairing roadside channels, etc.) which are the most time consuming?

What types of open roadside channels are in your area, and how are they performing in terms of sides being eroded, sediment deposits, maintaining vegetated cover (if vegetated), etc.? Any advice for engineers?

How are culverts performing? Do they often have to be cleaned out often? If so, inside and/or near entrance? Any advice for engineers?

Is work of crews entered into a computer? If so, what is database name, or describe system. Does the District Office have access to it from where they are?

How does maintenance decide what rehabilitation projects should come next?

Do you sometimes have ideas for making things better, but feel it's not listened to by engineers or other decision-makers? Explain, or give example(s).

Any advice/comments?

APPENDIX H: SURVEY OF FLOODPLAIN ADMINISTRATORS

Survey for Floodplain Administrator

Name:___________________________
Title:____________________________
Phone No.:_______________________
Entity (including city/county):____
Date:____________________________

Introduction:
As part of its philosophy that it should always seek to improve, TxDOT has hired UTSA to help it reduce the hydrologic/hydraulic impacts of its projects. As an FPA (*add other relevant credentials, such as "City Engineer", etc.*) who is not employed by TxDOT, your feedback regarding your working relationship with TxDOT is important to our work. We would appreciate your input.

1. At what stage of projects are you typically contacted regarding the project?

2. Do you receive a final set of plans and hydraulic calculations? What documents would you like to receive, and when?

3. Are you satisfied with the quality of your working relationship with TxDOT? Is there anything TxDOT might do to improve it?

4. Any other comments?

APPENDIX I: LIST OF ABBREVIATIONS

2DH	Two-dimensional flow in the horizontal plane
ASFPM	Association of State Floodplain Managers
B-CAP	Broken-back Culvert Analysis Program
AASHTO	American Association of State Highway and Transportation Officials
ACB	Articulating Concrete Blocks
BLM	Bureau of Land Management
BMP	Best Management Practice
BRINSAP	Bridge Inventory Inspection and Appraisal System
CFM	Certified Floodplain Manager
CFR	Code of Federal Regulations
CLOMR	Conditional Letter of Map Revision
CSS	Context-sensitive Solutions
DEM	Digital Elevation Model
DEP	Department of Environmental Protection
DHE	District Hydraulic Engineer
DOT	Department of Transportation
DTM	Digital Terrain Model
EDMS	Electronic Data Management System
FDA	Flood Damage Analysis
FEMA	Federal Emergency Management Agency
FESWMS	Finite-Element Surface-Water Modeling System
FHWA	Federal Highway Administration
FM	Farm to Market
FPA	Floodplain Administrator
GIS	Geographic Information System
GSSHA	Gridded Surface Subsurface Hydrologic Analysis
HCFCD	Harris County Flood Control District
HDM	Hydraulic Design Manual
HEC	Hydrologic Engineering Center
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HH	Hydrologic and Hydraulic
HOV	High Occupancy Vehicle
LID	Low-Impact Development
LIDAR	Light Detection and Ranging
LLC	Limited Liability Company
LMOR	Letter of Map Revision
Mass	Massachusetts
MBITS	Maintenance Bridge Inspection Tracking System
MOU	Memorandum of Understanding
MPE	Multisensor Precipitation Estimation
MPO	Metropolitan Planning Organization
NAI	No Adverse Impact
NCDC	National Climatic Data Center
NCHRP	National Cooperative Highway Research Program
NEXRAD	Next Generation Weather Radar

NFIP	National Flood Insurance Program
NHI	National Highway Institute
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
PICP	Permeable Interlocking Concrete Pavement
PS&E	Plans, Specifications, and Estimation
ROW	Right of Way
SH	State Highway
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Database
SWMM	Stormwater Management Model
TBPE	Texas Board of Professional Engineers
TFMA	Texas Floodplain Managers Association
TR	Technical Release
TVA	Tennessee Valley Authority
TxDOT	Texas Department of Transportation
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey