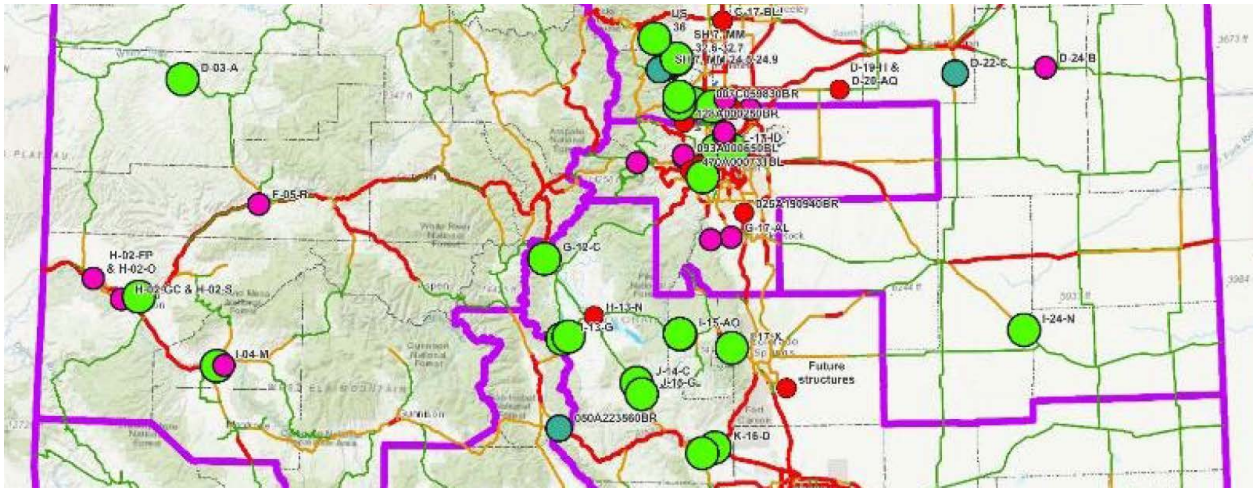
COLORADO
Department of Transportation

CDOT Applied Research and Innovation Branch



CDOT 2D Quick Checks Statewide Initiative

Kalli Wegren, PE, CFM; Brian Varrella, PE, CFM; Brian Campbell, PE, CFM

November 2022

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16. Abstract

The 2D Quick Check Statewide Initiative created a process where the Colorado Department of Transportation (CDOT) design projects are value engineered to improve safety, enhance efficiency, and reduce material costs early in the project delivery workflow. CDOT partnered with six consultants to develop 46 2D “Quick Check” (2dQC) models in 2021. Over the 46 2dQCs, $22.4 million in construction cost savings and resiliency benefits was identified. Another 108 design and safety innovations were discovered and documented. The success of the 2dQC initiative initiated a Phase 2 and Phase 3, so by 2024 there is a 2dQCprogram in place to reduce total project costs and streamline project delivery statewide.

Implementation (Optional)

The implantation of 2D Quick Checks involves (1) identifying a project-specific need or challenge, (2) collecting background information, (3) building a 2dQC model, and (4) sharing out results and alternatives to guide project decisions. Best practices, resources, and lessons learned were captured through the research initiative to help with these steps and are discussed in the body of the report. Through the initiative, a training curriculum was also developed to train internal and external partners on the 2dQC process and give others the knowledge and resources to implement 2dQCs statewide. The training course will continue to be offered through the next phases to ensure the success of this program continues and evolves over time.

17. Keywords	18. Distribution Statement
2D Hydraulic Modeling; 2D Quick Checks; 2dQC;Hydraulic; SMS; Project Support; Project Delivery	This document is available on CDOT’s website https://www.codot.gov/programs/research

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Project Overview

A portion of Colorado Department of Transportation (CDOT) pre-construction design projects delivered at the Region and Headquarters level can be value-engineered to improve safety, enhance efficiency, and reduce material costs using 2-dimensional (2D) hydraulic analysis "quick checks" at scoping, prescoping, and asset management levels of the CDOT Project delivery process. 2D hydraulic analysis software helped Region 4 staff at CDOT save $14 million in construction costs over a 3-year period by 2018. The in-house experience created a new statewide catalyst initiative that same year to reduce project costs up to $20 million annually while improving safety and enhancing project delivery efficiency. The initiative, deemed 2D Quick Checks (2dQC), developed a statewide process for all CDOT Regions with federal State Transportation Innovation Council (STIC) resources and state matching project and research funds.

Through the initiative, 46 individual 2D Quick Checks, or 2dQCs, were completed at the CDOT Project Pre-Construction Design scoping or pre-scoping phase. The 16 in-house CDOT 2dQCs were supplemented with 30 more 2dQCs developed by private firms working under contract for Region 4, including AECOM, Ayres Associates, Jacobs Engineering, Muller Engineering, RS&H, and RESPEC. All 2D analyses were completed using SMS/SRH-2D software from Aquaveo and supported by the Federal Highway Administration (FHWA). Short reports from each individual project were compiled into a Final Rollup Summary Report with conclusions and recommendations from the six private sector firms and five Region Hydraulic Engineers comprising the Technical Advisory Committee (TAC). A 1.5-day training curriculum was also developed with support from the CDOT Research Branch for internal staff and private sector consulting partners. An Executive Oversight Committee (EOC) of statewide CDOT Management personnel and FHWA Resource Center partners reviewed progress quarterly and considered recommendations from the Final EOC Presentation in March 2022, concluding a 20-month effort.

The 2dQC Phase 1 effort accumulated a substantial body of knowledge, savings opportunities, project enhancements, safety improvements, and new statewide protocols and actions to repeat these successes. Objectives for the entire effort are identified and discussed in their own section to follow. Deliverables identified in the Research Project scope of work included compiling results, conclusions, and best practices from completed 2dQCs, developing in-house expertise at the Region Hydraulic Engineer level, and modifying the project delivery processes to identify and execute 2dQC-eligible projects at scoping or pre-scoping, also known as project initiation. These objectives were completed in November 2021 and reported to the EOC in March 2022, and project deliverables were distributed to all five CDOT Regions. CDOT is now moving to Phase 2 to formalize a statewide 2dQC program.

Description of the Problem

Construction projects at CDOT are developed through a rigorous process of 10-year planning that is informed by public and regional transportation needs that are coupled with available fiscal resources. Project priorities are developed and advance from the planning phase to design phase, then ultimately to construction. An opportunity presented itself between planning and design phases, and the first spark of a 2dQC framework was discovered.

Recent evolutions in 2D hydraulic analysis tools from the FHWA have a high potential to reduce infrastructure design uncertainties in and near natural waterways, resulting in infrastructure construction projects that are more efficient, safer, and more cost effective. The 2dQC effort leverages the innovation of 3-dimensional terrain modeling in a 2D software package using statewide LiDAR and

as-built information. The technological leap from 1D to 2D software removes user-based input judgements to more accurately analyze infrastructure performance in natural waterways during design. This allows project scopes of work, as they migrate from a planning idea to a full design scope of work, to receive more detailed background information, more clear understanding of risks and opportunities, and an enhanced view of how proposed infrastructure improvements or modifications can interact with the natural environment. 2D "quick checks" are back-of-the-envelope hydraulic analyses that make it possible to identify project element enhancements, identify previously unseen project risks, offer mitigation alternative for all identifiable risks during the scoping phase of a design project, and quantify the benefits of those recommended enhancements and alternatives. If applied during the scoping of a design project, they have the greatest impact on improving safety, optimizing resources in a fiscally constrained environment, and improving the overall effectiveness of constructed elements delivered on CDOT projects.

CDOT Region 4 staff were the first DOT personnel in the nation to quantify the demonstrable benefits of 2dQCs, and they were able to approach project scoping process changes with informed optimism. The Region 4 Hydraulics Unit Lead and private-sector design teams applied a 2D hydraulic analysis process to 27 projects over a 3-year period to reduce construction costs by $14 million and improve the safe function of projects including highway revetment projects, bridge replacements, traffic signal control installations, and environmental restoration projects. All of these savings were discovered midway through the design process, and while resulting in savings and improvements, a team of experts at CDOT and six private firms were confident a proactive program could achieve similar outcomes with less disruption to scope, schedule and budget in the design process by applying the same process earlier in the project timeline.

The 2D Quick Check Statewide Initiative was created in partnership with the Office of Process Improvement (OPI) at CDOT Headquarters in 2018. The initial "quick check" project support strategy and analytical framework were developed through a Project Charter to measure prospective CDOT project potential for adapting to 2dQC insights prior to design execution. Over the course of the initiative, $22.4 million in quantifiable benefits were identified in addition to 108 innovations and safety enhancements. The 2dQC is considered a success in the Phase 1 proof of concept, and is moving to a Phase 2 in 2023 to develop a formal program supporting project delivery across Colorado. Implementation is expected in Phase 3 by 2024.

Funding Sources

A final budget was prepared in May 2019 consistent with Project Charter objectives to apply for STIC grant and CDOT Research Branch funding. It was modified in December 2019 as the scope of work expanded to include the development of training curriculum and internal staff development goals associated with Project Charter lead and lag measures. The minimum budget initially required to meet all goals and objectives was identified as $414,454, and the final budget received from all revenue sources totaled $425,760.

The breakdown of funding sources and subtotals is as follows:

	$85,000	=	Federal STIC Grant Funds (FY2019 award from EDC-5)	=	20.0%
	$19,815	=	Federal STIC Unused Funds Supplement (FY 2020)	=	4.7%
	$222,945	=	State of CO HQ120 Funds (Headquarters)	=	52.3%
	$15,000	=	State of CO RPP20 Funds (Regional)	=	3.5%
+	$83,000	=	State of CO Research Funds (Headquarters)	=	19.5%
	$425,760	=	Total budget, all sources	=	100.0%

The funding breakdown indicates the total 2dQC effort was supported by 25% federal grants and 75% state funds. STIC funding requires a 20% match, and CDOT was able to over-supplement the minimum requirement to the benefit of all parties and partner agencies. CDOT sincerely appreciates the support from the Research Branch to make Phase 1 of 2dQC possible and the guidance on implementation so the entire agency can realize the benefits statewide.

Research Objectives

The Research component of the 2dQC statewide initiative was funded as Project 24149, and 46 individual projects were actually delivered under Project 23532. The three Research objectives were satisfied with outcomes that exceeded expectations. The first objective to institutionalize 2dQCs at project scoping was achieved with collaboration with the Headquarters (HQ) Resilience Program led by Lizzie Kemp, and with assistance from the PRTO Division. The workflows, how-to videos, past project reports, and GIS Library developed while delivering 46 projects statewide are in the process of being archived through OnBase, and a new pre-scoping (initiation) and scoping check box will be added to PMWeb to encourage Resident Engineers and Project Managers to glance at Quick Check opportunities. Check boxes will be strategically located next to a Resilience check box in PMWeb, and since both the Risk and Resilience Calculations and 2dQCs complement one another, this will enhance opportunities to discover value from both programmatic functions in the future. More importantly, the check boxes in PMWeb will flag attention to the GIS library with visual cues to the user to pull down complete hydrology studies, hydraulic analyses, and risk and resiliency calculations to inform and accelerate pre-construction design efforts.

The second objective of enhancing safety, design effectiveness, and costs was satisfied with a combination of successes developed in project delivery (23532) that were analyzed with Research funds (24149). Quantifiable benefits of all efforts amounted to $2.8 million in construction savings, $1.5 million of deferred project opportunities, and $18.1 million of resilience benefits, totaling $22.4 million of total project benefit. The return on investment (ROI) for the entire program was 53:1, and for the projects under 23532 the ROI was 115:1, which exceeded the initial goal of 80:1. Additionally, the assistance provided by six engineering firms on 30 of the 46 projects delivered resulted in 108 innovations captured and documented in the training curriculum currently being delivered statewide to transfer 2dQC knowledge to all CDOT Regions.

The third and final objective for the Research portion of the 2dQC program was to develop a 1.5-day training program. The training was fractured into three segments for vision and software introduction, results troubleshooting, and building a 2dQC at the end; this curriculum was delivered in three different training efforts across the state in 2021. The alpha test included Region 5 Hydraulics and Design Unit staff in July 2022, the beta test was completed at Muller Engineering with their staff shortly thereafter, and the final training event was hosted in November 2021 for HQ and Region Hydraulics Staff and Design Unit staff at CDOT HQ. The shortened curriculum was used for a workshop during the Colorado Association of Stormwater and Floodplain Mangers annual conference in September 2022. The full 1.5-day curriculum is under revision for enhancement and use for Phase 2 training events with internal staff,

and with our external consulting partners from 2022 into 2024. The GIS library of resources will allow internal and external customers the opportunity to borrow templates and workflows to prepare 2dQCs in the future, and a decision-matrix was prepared for fast reference to help determine whether or not a 2dQC is appropriate or helpful on upcoming projects and planning efforts.

Results

The 2dQC *Phase 1 (Experimentation)* effort received notice to proceed in July 2020 and concluded in March 2022. The project was so successful that it is now moving to *Phase 2 (Process Development)* in 2023 and *Phase 3 (Statewide Implementation)* in 2024. The program efforts succeeded beyond all expectations; here is a list of some of project deliverables;

- Identified a total **quantifiable benefit of $22.4 million** (see **Figure 1**)
- Return on investment **(ROI) = 115:1 for projects**, and 43:1 for the total program
- Completed **46 2dQCs across the state with 109 innovations** (**Attachment A**)
- Developed a GIS library to **reduce the cost of future CDOT Design projects by 10%** per 2dQC
- Created a Hydraulic Toolbox Decision Matrix (**Attachment B**) for proper application of 2dQC
- Developed protocols to complete 2dQCs within 20 hours, from initiation to results reporting
    - A template memo to easily communicate 2dQC opportunities with Project Managers and others (**Attachment C**)
    - A spreadsheet of 2D hydraulic modeling best practices (**Attachment D**)
- Prepared a **1.5-day training curriculum** and presented on 3 occasions (ready for external delivery). A copy of the training curriculum agenda is included as **Attachment E**.
- Secondary outcomes
    - Closer collaboration and partnership with the CDOT Resilience Program and Staff Bridge asset management functions
    - Shared Colorado 2dQC experiences with other DOTs across the nation through an FHWA 2D Hydraulic Modeler's Forum (April 2022)
    - Promoted 2dQCs internally and externally through presentations and demonstrations at the following events: CDOT PE II meeting, CASFM Lunch and Learn, Area Engineer Newsletter, Aquaveo (software development & training team), Region 4 Base Course, ACEC Denver Conference, and the Colorado Flood Technical Assistance Partnership
    - Presented the 2D Quick Check initiative and results at the National Hydraulic Engineering Conference in August 2022.
        - This prompted other departments of transportation (DOT) and companies to seek out CDOT's assistance and resources to develop a similar program in their area. The program team has sent resources directly to Kansas DOT, North Dakota DOT, Idaho Transportation Department, Garver USA (Alabama), and Aquaveo.
    - Identified 20 new 2dQCs to be completed in 2023 and 2024 (and the list is growing)
    - Discovered and developed additional resources to streamline 2D hydraulic modeling and project delivery such as Colorado Hazard Mapping & Risk MAP Portal and internal 5-minute training videos.

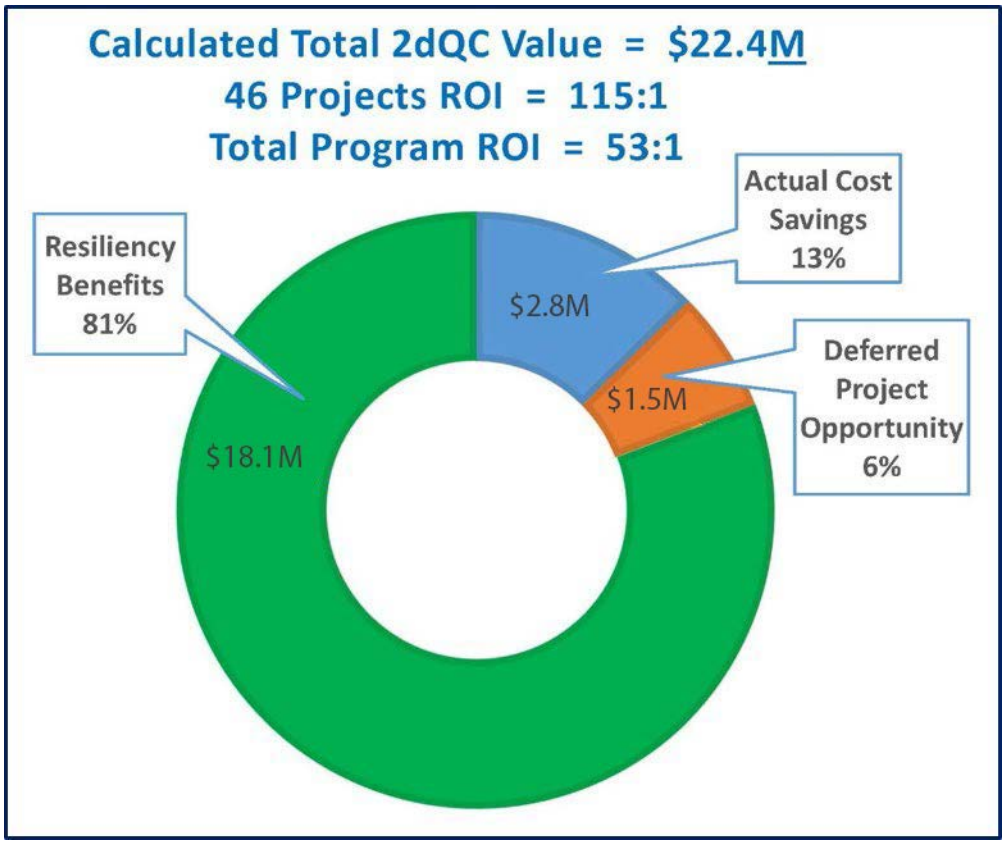


Figure 1. Total 2dQC project benefits

CDOT hosted 5 TAC meetings and 5 EOC meetings over the 20-month period from July 2020 to March 2022. The EOC supported a strategic plan to establish a formal program in Phase 3 supporting the project delivery process. This program would be managed at a Headquarters level with a statewide guiding committee of subject matter experts (SMEs) from Headquarters and each of the 5 CDOT Regions. It would also oversee and maintain the transfer of knowledge by managing a GIS library of hydrology basins, 2dQCs, and supporting documents and technical analyses archived for future access using OnBase. This information will be shelf-ready for other CDOT and FHWA design efforts on state and federal highways, and as the library grows over time, will reduce the cost of future design projects by 10% (estimated).

The 2dQC Phase 1 process aligned well with other statewide efforts, including the Resiliency Program calculation tools development, and the PMWeb project management rollout. These analyses are also instrumental to improving right-of-way and environmental clearances, jump-starts hydrology and hydraulic analyses, and identifies fatal flaws at project scoping that are not historically evident until 30% or 60% completion. Funding for Phases 2 and 3 will be explored once the draft Strategic Plan is completed and an Executive CDOT Champion is identified.

Challenges and Lessons Learned

Challenges and lessons learned were captured over the course of the initiative so discoveries could be carried forward to future phases. Here is a list of project challenges;

1. Initial resistance to learning new software (internal CDOT staff).

    a. Hydraulic Engineers at CDOT are extremely busy and do not have adequate time for in-depth training.
    b. The desire to learn new processes with 2dQC is strong, but there is fear that other tasks will not be completed and employees may experience pushback or other negative consequences.
2. Initial supervisory support for more training must precede the use of new technology before new efficiencies can become reality.
3. Initial supervisory support for re-prioritizing of tasks and how they may be completed with blended teams of consultant support is required before adequate time can be devoted for training and regular implementation of 2dQCs by in-house CDOT staff.
4. A vision to make Hydraulics relevant in CDOT project delivery system must precede the use of new technology.
5. Bentley software struggles to be compatible with other software, including SMS/SRH-2D and HEC-RAS 2D, the primary 2dQC software platforms in the transportation engineering industry.

Here is a list of lessons learned throughout the project;

1. Headquarters leadership would be most effective to roll out a 2dQC Program statewide at CDOT, but there is currently no Headquarters champion.
    a. Next phases of 2dQC must be led from CDOT Region 4 (Hydraulics Unit in Greeley) and Region 5 (Hydraulics Unit in Durango).
    b. Programmatic changes are needed to make Hydraulics more relevant in the CDOT Project delivery system, especially PMWeb software and the Project Delivery Manual currently being updated (see previous bullet point).
2. A funding pool is needed to support 2dQCs long-term at $2,000 per site for internal work, and $7,000 per site for consultant-led efforts.
    a. This cost will escalate with wage growth and requires metrics be reviewed continuously to map trends and needs before budgets are reviewed annually.
    b. Total annual costs are expected to exceed $170,000 initially, which assumes 30 projects can be completed per year, half in house and half with consulting, and all with a 26.5% overhead rate.
3. Inserting a 2dQC into a project design effort requires prior planning; most effective to use it to inform the scope of work before it is complete.
    a. CDOT is not consistent at pre-scoping or project initiation review meetings, and too often rushes into a final scope of work; a 2dQC is more disruptive later in the project delivery workflow.
    b. Recommend all DOTs use pre-scoping review meetings to create efficiencies and mitigate potential fatal flaws, and make 2dQC opportunities possible and effective.
4. A list of 108 innovations and best practices is shown in **Attachment F** and requires visibility to be effectively put to use on future projects; a vector for sharing these lessons is neither available at a Region level nor a statewide level, and should be a challenge identified in Phase 2 and mitigated in Phase 3 of the 2dQC programmatic rollout.

Implementation

The 2dQC statewide initiative improved safety, led to design innovations, and saved project costs. The benefits this process has for CDOT made it critical to develop an implementation plan for continued success. The following fundamental steps are endorsed for the creation of future 2dQCs;

1. Identify a project or asset at the planning, pre-scoping (initiation) or scoping phase of CDOT Project Delivery, and clearly define the problems that can be identified and potentially addressed with a 2dQC; define the challenge or need.
2. Collect background information, including free statewide LiDAR topography, hydrologic boundary conditions, and as-built plans or pre-construction design concepts.
3. Develop a 2dQC on a Tier 1 through Tier 3 process.
    3.1. Tier 1 - in house 2dQC from statewide team (Kalli, Brian C. and Brian V.) with Region oversight, and;
    3.2. Tier 2 - same as Tier 1, except the affected Region will lead the analysis with statewide assistance, and;
    3.3. Tier 3 - blended team of NPS Contractors and CDOT in-house staff with Region oversight.
4. Prepare brief summary of results and present to Region Project Engineers, Project Managers, Resident Engineers and/or Program Managers for final decisions. Options will include implement in whole, implement in part, re-analyze, any combination of the preceding, or decline all. All information, models, and deliverables will be available to assist with current and future project delivery.

A statewide panel of subject matter experts will be created in Phase 2 to identify and filter 2dQC opportunities at the project planning level. The resources for projects years 1-4, projects years 5-10, the 10-year vision, and asset management lists will be utilized to filter potential 2dQCs. PMWeb will be utilized by Project Managers and Region Hydraulic Engineers to go or no-go 2dQC opportunities and ensure a 2dQC is completed at pre-scoping to scoping level. As described in the list above, there is a tiered system with options for in-house, external, or blended teams to complete 2dQCs. All 2dQC models, results, and data will be housed in OnBase and included in the GIS data library.

2D Quick Checks will streamline required project hydraulics tasks and be another tool to help with CDOT's work to "provide the best multi-modal transportation system for Colorado that most effectively and safely moves people, goods, and information."

Attachments

Attachment A – Statewide 2dQC Projects

Attachment B – Hydraulic Design Decision Matrix

Attachment C – 2dQC Memorandum Template

Attachment D – 2dQC Best Practices

Attachment E – Training Curriculum Agenda

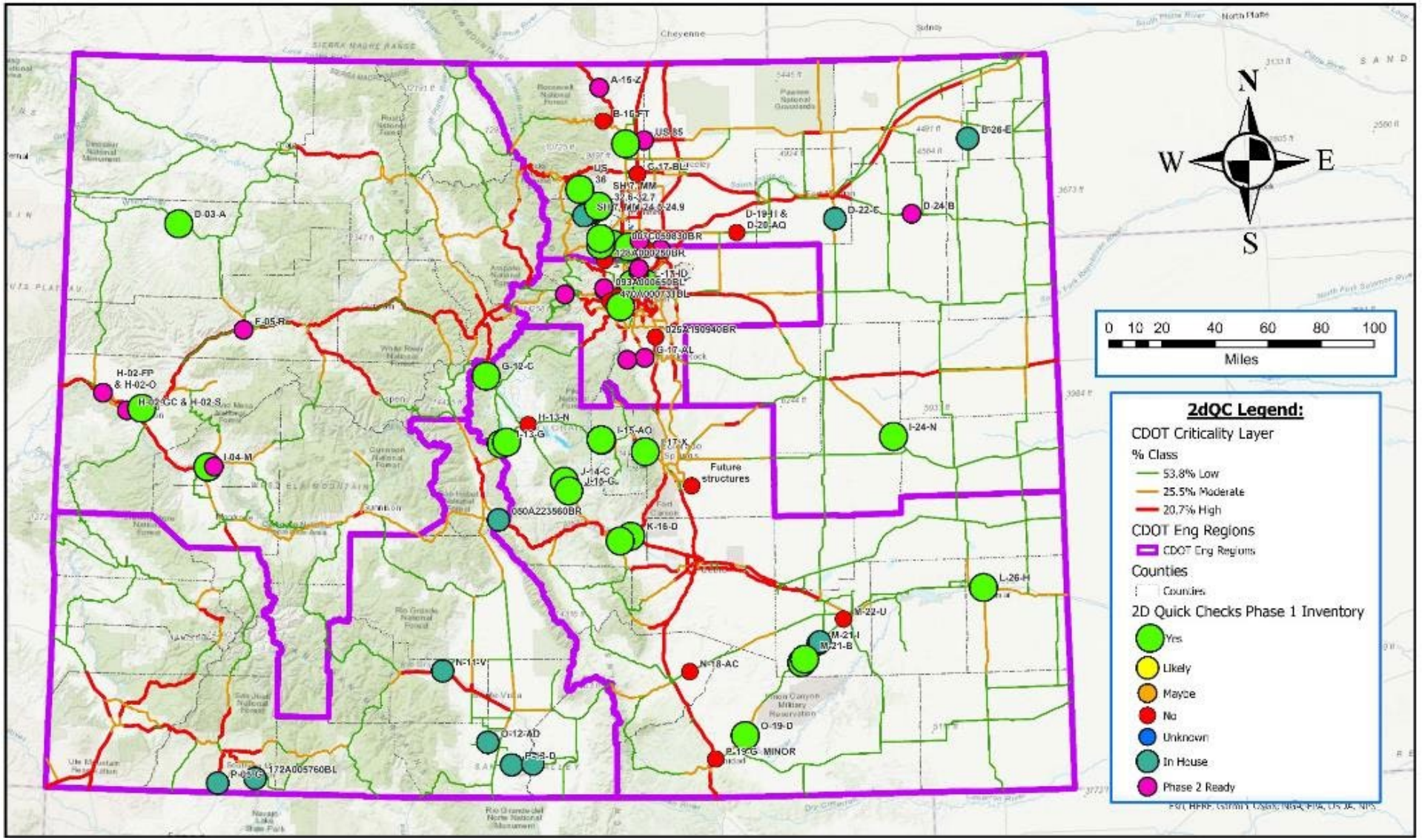
Attachment F – Innovations Summary

Attachment A

COLORADO DEPARTMENT OF TRANSPORTATION
STATEWIDE INVENTORY OF 2D QUICK CHECKS, PHASE 1 (23532)

COLORADO Department of Transportation

Last Update: February 21, 2022



Statewide 2dQC projects completed in Phase 1 (“Yes” and “In-House”) totaling 46, and Phase 2 Ready projects currently standing at 20.

Hydraulic Design Decision Matrix (Peer Review Still Continuing)				
A score of 1 indicates a great tool for the application, 2 use with caution, and 3 not the best tool for the job				
Application	Basic Calcs	1D Model	2D Model	Available Tools *(not exhaustive)*
Small Culvert Sizing (<48")	1	1	3	HY-8, HDS-5, FHWA Toolbox, Flowmaster, MHFD Tools, HEC-RAS, CDOT Risk & Resiliency Spreadsheet
Minor Culvert Sizing (≥48")	1	1	2	HY-8, HDS-5, FHWA Toolbox, Flowmaster, MHFD Tools, HEC-RAS, CDOT Risk & Resiliency Spreadsheet
Major Culverts/Bridges Sizing (Span ≥20')	2	1	1	HY-8, HDS-5, HEC-RAS, SMS/SRH-2D, Culvertmaster, CDOT Risk & Resiliency Spreadsheet
Split Flow	2	2	1	HY-8, SMS/SRH-2D, HEC-RAS
Unsteady Flow Routing	3	1	1	HY-8, SMS/SRH-2D, HEC-RAS
Identify Asset Risk	1	1	1	HY-8, FHWA Toolbox, SMS/SRH-2D, HEC-RAS, CDOT Risk & Resiliency Spreadsheet
Riprap Sizing	2	2	1	FHWA Toolbox, HEC-RAS, MHFD Tools, HEC-23, SMS/SRH-2D
Scour Analysis (Expansion/Contraction)	3	2	1	Offline spreadsheet, FHWA Toolbox, SMS/SRH-2D, HEC-18
Roadway Overtopping	2	2	1	Offline spreadsheet, FHWA Toolbox, SMS/SRH-2D, HEC-RAS, MHFD Tools, CDOT Risk & Resiliency Spreadsheet
Floodplain Permitting	2	1	2	HEC-RAS, SMS/SRH-2D, Offline spreadsheet, survey data, Local Agency Tools
Pre-Construction Clearances	2	2	1	HY-8, FHWA Toolbox, HEC-RAS, SMS/SRH-2D, Local Agency Tools
Safety Planning	1	1	1	**When it comes to safety, use all available tools!**

Hydraulic Toolbox Decision Matrix to help guide CDOT Project Managers and Specialty Units determining which hydraulic analysis tools are best suited to design projects and project functions.

Every Day Counts 5 (Edc-5) Memorandum

2d Quick Check Hydraulic Analysis

Date: [date]

From: [name, credentials -- *company & title*]

To: [CDOT PM, credentials -- *title*]

CC: Kalli Wegren, PE, CFM -- *CDOT 2D-QC Project Manager*

Brian K. Varrella, PE, CFM -- *CDOT 2D-QC Project Lead*

Subject: 2D Quick Check of [risks] repair features at [CDOT Road] in the [Waterway], [County], Colorado (*CDOT Project Code #####*)

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1. Purpose And Intent

The Colorado Department of Transportation (CDOT) partnered with [consultant] to prepare a series of 2-dimensional (2D) hydraulic analysis quick checks. This partnership utilizes state of the art 2D hydraulic analysis software package SMS/SRH-2D, endorsed by the Federal Highway Administration (FHWA), to better understand how infrastructure interacts with the natural environment on Colorado's rivers and waterways. This effort is led statewide under CDOT's participation in the FHWA Every Day Counts (EDC) program for Collaborative Hydraulics: Advancing to the Next Generation of Engineering (CHANGE).

This 2D quick check exercise intends to investigate, confirm, review or otherwise explore the following project components and functions [modify at least 3 of the following or add your own]:

1. Investigate new structure type, size and/or configuration
2. Investigate design modification (to site or channel or roadway elements)
3. Investigate/verify new/modified/alternative revetment material, size and/or configuration
4. Assess stability of roadway prism against erosion
5. Assess stability of roadway embankment against erosion
6. Assess level of service/protection of roadway during known flood events
7. Explore alternative design hydrology thresholds/values
8. Site traffic signal appurtenances against identifiable flood risks
9. Verify/Modify selected scour plans of actions and associated treatments

All conclusions and recommendations herein are offered as guidance to the CDOT project delivery process to identify potential safety improvements, efficiency enhancements, and material cost savings. **Recommendations are advisory, and intended to inform project delivery decisions by CDOT Project Mangers, Resident Engineers, Asset Managers, and Program Managers at their sole discretion**. All analyses are considered conceptual or "back-of-the-envelope" in nature, and while they may inform final analyses, reports, plans, specifications and estimates, they shall not be considered complete at the time of this memorandum (memo).

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2. Conclusions And Recommendations

The 2D quick check analysis was prepared in partnership with CDOT's EDC-5 effort to [describe what you hope to achieve, consistent with next section]. [Offer executive summary of a few conclusions here, but no more than 2-3 sentences.]

We are pleased to recommend the following project opportunities for consideration by the project management team:

1. Safety Improvements
    a.
2. Efficiency Enhancements
    a.
3. Material Cost Savings
    a.

3. Project Background Information

Describe project you are analyzing; goals of project, goals of the analysis (and how they fit the project), location, approximate timeframe, and infrastructure assets we hope to analyze/protect/improve.

Add or attach a vicinity map; scale, north arrow, identify highway, identify water feature, and identify assets considered in analysis.

State in 2-3 sentences what the quick check intends to discover, solve, resolve or achieve.

Provide a short paragraph describing the nature of hazards and risks at the site, and how they relate to existing or planned/proposed CDOT infrastructure.

Specific location information for the general study area are listed as follows:

CDOT Region:	**4**
Waterway:	**N. St. Vrain Creek**
County:	**Boulder**
CDOT Road:	**SH 7**
Structure(s):	**D-15-A [or N/A if no structures]**
Scour Critical?:	**Yes/No [or N/A if no structures]**
Mile Post:	**32.97**
Project Name:	**SH 7 Lower PR**
Subaccount:	**20252**
Latitude:	**40.22257**
Longitude:	**-105.271597**
Flood Zone:	**Zone AE [or N/A if not in NFIP inventory]**

Identify any plans, record drawings, as-builts, reports, ground survey, inspection documents, or any other background information pertinent to this quick check.

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4. Hydrology, Hydraulics And Background Data

4.1. Background Data Collection

All ground topography was acquired from [state sources, including LiDAR] and merged into a terrain model or surface. Light Detecting and Ranging (LiDAR) information was acquired from the Colorado Hazard Mapping and Risk MAP Portal (CWCB 2020) and utilized as a baseline for elevation information of the 2D quick check. [Insert a sentence for other survey info, if available and utilized, and briefly describe how terrain was merged to a single surface]. Vertical elevation information prepared for this memo is projected in units of feet in the North American Vertical Datum of 1988 (NAVD88). Horizontal information is projected in feet in the Colorado State Plane [North, Central or South] region of the North American Datum of 1983 (NAD83, Colorado State Plane, North/Central/South). Any CDOT plan sheets projected in a Modified State Plane horizontal datum include a ground-to-grid conversion in the CDOT Project Control Diagrams included as **Attachment X**.

Identify other documents; geotech reports, as-builts, record drawings, inspections, bridge plans, drainage reports, scour POAs, structure selection reports, etc.

4.2. Hydrologic Information

The design discharge at the Project [#####] 2D quick check site conforms with guidance in Chapter 7, Table 7.2 of the CDOT Drainage Design Manual (CDOT 2019). [continue, and keep it brief].

Report discharges for the 10-, 25-, 50-, and 100-year storm events from published FEMA FIS info, regional/local master plans, watershed reports, or other government agency sponsored publication if available.

If a 500-year discharge is reported in a Scour POA, add to the quick check.

If published discharges are unavailable, please prepare a quick hydrologic analysis and describe means & methods for calculating the 10-, 25-, 50-, and 100-year discharge. If discharges were developed in-house by CDOT staff, request a summary to add as text. If discharges require a rainfall-runoff study, please request one from Project Manager Kalli Wegren (CDOT Region 4).

4.3. Hydraulic Analysis

[AECOM / Ayres / Jacobs / Muller / RESPEC / RS&H] created a series of two-dimensional (2D) hydraulic models using Aquaveo's SMS Version 13.X.Y (Aquaveo 2020) graphical user interface with the SRH-2D calculation routine. A series of 2D models was developed that included [reference data sources from previous sections] to analyze the hydraulic impacts of [waterway] on [infrastructure features]. Digital hydraulic analysis files from these 2D quick checks are identified in **Table 1** and are included in CDOT's Google Drive folder for Project 23532.

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Table 1. SMS and SRH-2D simulation file structure for 2D quick check.

Simulation	File Type	File Name or Coverage Name	SRH-2D Location
All Simulations	SMS Project File (*primary file*)	*#####_HWY_WATERWAY_ FIRM_2DQC.sms*	Project
	SMS materials info (roughness)	*#####_HWY_WATERWAY_ FIRM_2DQC.materials*	
	SMS map points, lines & polygons	*#####_HWY_WATERWAY_ FIRM_2DQC.map*	
	SMS mesh elevation definitions	*#####_HWY_WATERWAY_ FIRM_2DQC.h5*	
	SMS simulation commands	*#####_HWY_WATERWAY_ FIRM_2DQC.db3*	
	Aerial photographs	**.tif*	GIS Data
	LiDAR Rasters	**.**	
	TINs, DEMs, Shapefiles, etc.	**.**	
First Simulation	2D mesh with elevations	*Name*	Mesh Data
	Scatterpoint file (if applicable)	*Name*	Scatterpts
	Map coverage to create mesh	*Name*	Map Data
	Materials to assign roughness	*Name*	
	Boundary Conditions *	*Name*	
	EX SRH-2D simulation setup	*Name*	Simulation
	EX solution folder	*Name*	Folder
Second Simulation	2D mesh with elevations	*Name*	Mesh Data
	Scatterpoint file (if applicable)	*Name*	Scatterpts
	Map coverage to create mesh	*Name*	Map Data
	Map coverage to create mesh	*Name*	
	Materials to assign roughness	*Name*	
	Boundary Conditions *	*Name*	Simulation
	EX SRH-2D simulation setup	*Name*	Folder

* Indicates the same 100-year boundary condition was applied to both existing and proposed simulations.

If structures exist or will exist later, describe

Discuss materials coverage assignments; Hydraulic roughness (or Manning's-n values) assigned to the materials coverage was approximated by [existing 1D or 2D model, aerial photography, ground photos, field reconnaissance, etc.]. **Table 2** lists the different materials and associated roughness assigned through SMS, and **Attachment X (Y pages)** shows material locations and meshes for all 2D quick check hydraulic simulations.

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Table 2. Material and assigned hydraulic roughness for SRH-2D simulations.			
Material ID	Material Type	Hydraulic Roughness	Description
1	Unassigned	None	Obstructed flow areas; homes, bridge piers, silage, and areas not inundated by 100-year floodwaters.
2	Asphalt	0.020	Driving surfaces of CR 54E and US 287 (SH 14).
3	Channel	0.043	Main channel conveyance area of the Poudre River.
4	Pastures	0.040	Overbank agricultural lands, groomed fields, pastures and other grazed lands.
5	Forests	0.080	Riparian forests; largely comprised of cottonwood stands with shrub and taller grass undergrowth.
6	Riprap	0.055	9- and 12-inch D_{50} loose rock revetment.
7	Irrigation	0.025	Irrigation canal and appurtenances.
8	Buildings	0.800	Proxy for gap in mesh to block conveyance

Discuss 2d model boundary conditions

4.4. Hold for something else

Other text as needed

5. Results, conclusions and recommendations

Repeat the purpose of your 2d quick check -- what did you hope to discover, solve, resolve or achieve?

Discuss results briefly. Tell your story with pictures; embed JPGs or other exported features from SMS here with annotation.

Conclusions:

1.

The 2D quick check team is pleased to offer the following recommendations to the project management team at CDOT Region [X]:

2. Safety Improvements
    a.
3. Efficiency Enhancements
    a.
4. Material Cost Savings
    a.

The 2D Quick Check Team sincerely appreciates the collaboration with [PM Name] at CDOT Region

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[X], and for allowing us to identify opportunities to assist the successful delivery of Project [#####]. We hope the guidance offered herein is helpful and beneficial, and we are available to answer questions and provide further guidance or assistance as needed.

6. References:

Aquaveo; *Surface-Water Modeling System (SMS)*. Created under partnership with the Federal Highway Administration (FHWA), U.S. Army Corps of Engineers (USACE), and ESRI, 64-bit Version 13.1 (2020).
Available at *https://www.aquaveo.com*.

Colorado Department of Transportation (CDOT); *Drainage Design Manual (DDM)*. Acknowledgement, Table of Contents, and Chapters 1 through 18 (2019).
Available at *https://www.codot.gov/business/hydraulics/drainage-design-manual*.

Colorado Hazard Mapping & Risk MAP Portal; a collaborative digital information library hosted by the Colorado Water Conservation Board (CWCB) and managed by the Governor's Office of Information Technology (OIT).
Available at *http://coloradohazardmapping.com/*.

Hydrologic Engineering Center (HEC), *HEC-RAS, River Analysis System Hydraulic Reference Manual*. U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) Report No. CPD-69, Version 5.0 (2016).
Available at: *http://www.hec.usace.army.mil/software/hec-ras/*.

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7. Attachments:

Attachment A – Vicinity Map

Attachment B - Hydrologic Reference (published FEMA FIS info, regional/local master plans, watershed reports, or other government agency sponsored publication)

Attachment C – SMS/SRH2D Output

Attachment D – Plans, record drawings, as-builts, reports, ground survey, inspection documents, or any other background information

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Department of Transportation

Project Name: 2D Quick Check Statewide Initiative
Location: All Regions Statewide

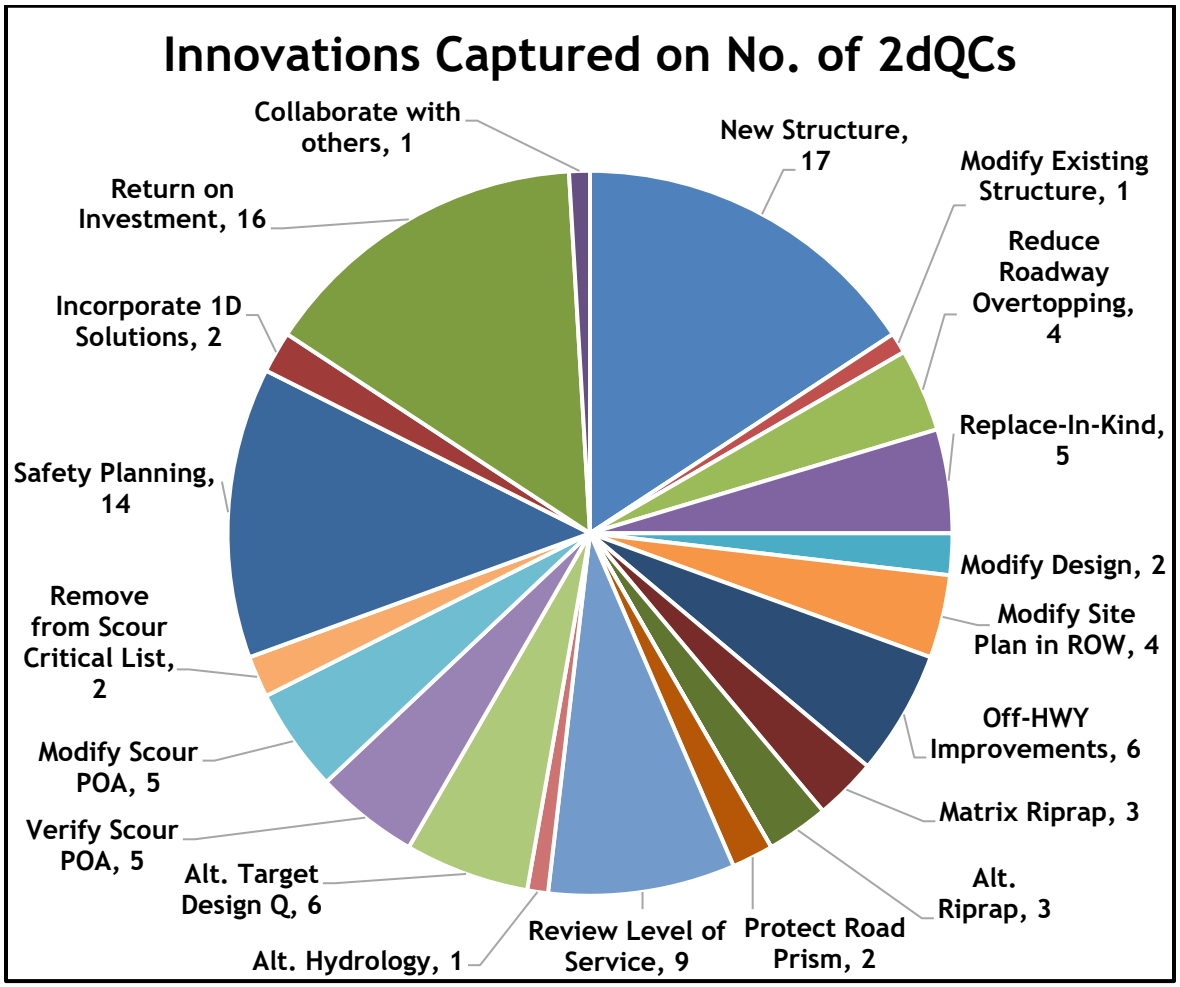
#	Originator or Team	Practice Level	Best Practices, Innovations, and Experiences	Next Steps or Resource Link
1	CDOT R4	Standard Practice	Set Boundary Condition Unsteady Output to "Off" **Right click BC map data > BC Types > Unsteady Output**	
2	CDOT R4	Standard Practice	Set Initial Condition in Simulation Model Control to "Automatic" **Right click simulation > Model Control > General Tab > Scroll down to Initial Condition**	
3	CDOT R4	Standard Practice	Use arcs to breakline all critical features in topography (channel, toe/top of slopes, edge of pavement)	
4	FHWA	Better Practice	Use the largest timestep that provides continuity	
5	CDOT R4	Standard Practice	Increased detail at contraction and expansion zones	
6	Muller, FHWA	Better Practice	Use continuity to check model results, especially for next-level analyses.	Add as a recommendation for design team.
7	Ayres, Muller, CDOT R4	Innovation Opportunity	Reduce standard equations in HEC-23 Vol. 2 to create heat-map of shear stresses to size revetments for roadway overtopping, embankment protection, and bridge scour.	https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=23&id=143 HEC-23 Derivation: https://drive.google.com/drive/folders/1fep4q85crLC4IFWM6-YUAeoCT1R3UOQj?usp=sharing
8	CDOT R4	Better Practice	Add Manning's-n value to title of legend and discharge value in name of Boundary Condition for rapid QC and ease of review	
9	CDOT R4	Better Practice	Create a Modified State Plane projection in the CDOT Ground Coordinates system for any project from Project Survey Control Diagram Scale Factor, False Easting, and False Northing.	https://drive.google.com/drive/folders/1fep4q85crLC4IFWM6-YUAeoCT1R3UOQj?usp=sharing
10	RESPEC	Better Practice	Plot a structure using the Plot Data coverage in the Map module. You can then see the structure in an Observation Profile plot.	https://www.xmswiki.com/wiki/SMS:Plot_Data_Coverage#:~:text=The%20Plot%20Data%20coverage%20is,conjunction%20with%20an%20Observation%20coverage.
11	CDOT R4	Standard Practice	Run 1D HY-8 first to compare results to HY-8 results from 2D model.	
12	FHWA	Standard Practice	If you have multiple culverts in a model, enter all culverts into a single HY-8. Use unique (simple) names for each culvert crossing. These names are used to differentiate between culverts.	
13	FHWA	Standard Practice	Plan your mesh so that a row of elements generally represents the width and alignment of the culverts. The width can be represented by one or more elements.	
14	FHWA	Standard Practice	Ensure that the mesh elevations are reasonably representative of culvert inverts.	
15	FHWA	Standard Practice	Place the BC arcs at the upstream and downstream ends of the culvert, with the width generally representing the width of the culvert group.	
16	FHWA	Standard Practice	When a road embankment across the channel is represented in the mesh, the BC arcs will located across the channel inverts at the up and downstream ends. However, when the channel cut is represented in the mesh, the BC arcs must be drawn to extend across the entire opening to prevent flow from going around the culvert zone.	
17	FHWA	Standard Practice	The crest length in HY-8 should represent the overtopping that exists within the 1D area. In most cases, the crest length will be equal to the arc length (more accurately the width of elements that the arcs are mapped to). Any overtopping outside of the 1D zone is computed within the 2D mesh.	
18	FHWA	Standard Practice	In SMS 13.1 (SRH 3.3), a new option is added to compute overtopping in the 2D mesh. When this option is selected the HY-8 BC arcs are treated as Link boundaries and the elements between them no longer need to align with the culverts. When the 2D overtopping option is used, the elevation of the embankment in HY-8 needs to be artificially raised to prevent double accounting of the overtopping flow. Alternatively, the width of the overtopping could be set to a very small value to still preserve the embankment profile in HY-8.	
19	FHWA	Standard Practice	In most cases, the steady flow option works fine, but when there are problems with instabilities, changing to the unsteady flow option can resolve the problems.	
20	CDOT R4	Better Practice	Include notes in coverages' "Metadata" to keep track of analysis decisions, assumptions, information, etc. **Edit > Project Metadata** OR **Right click Simulation > Tools > Summary Report (beta)**	
21	CDOT R4	Standard Practice	Use DEM LiDAR data (vs LAS data). DEM data is easier to use, trim, and bring into SMS.	
22	RESPEC	Better Practice	Use Angle Representation Region plot to measure mesh quality. **Plot Wizard > ARR Mesh Quality > Finish**	
23	AECOM	Better Practice	New online maps are available in SMS v 13.1 such as FEMA Flood Hazard Zones (can be used for reference or to compare results to 1D solution). **Get Online Maps > Advanced > USA Flood Hazard Zones > Ok** **Right click new layer to change transparency**	
24	CDOT R4	Innovation Opportunity	Use Source Arc to quickly build a mesh between 2 curving arcs. **ID 2 acrs > Select 2 arcs > Redistribute Vertices > Under Specify choose " Source Arc" > Identify Source Arc & Target Arc > OK**	https://xmswiki.com/wiki/SMS:Arcs Link to video clip tutorial: https://drive.google.com/drive/folders/1fep4q85crLC4IFWM6-YUAeoCT1R3UOQj?usp=sharing
25	Jacobs	Better Practice	When placing an upstream BC place the BC line the same width as the floodplain you are modeling. If a width is unknown estimate the width using a normal depth calculator such as Bentley FlowMaster or Hydraulic Toolbox.	
26	Jacobs	Better Practice	When placing a downstream BC make the BC line 1.5 times wider than the anticipated floodplain to avoid ponding water and affects to WSEL at the BC line.	
27	Jacobs	Better Practice	When selecting a timestep, consistently stable results occur near a 40:1 ratio, with the ratio representing average mesh element size to timestep in seconds (mesh element : timestep). For faster results consider a larger ratio up to a 10:1 where results begin to become unstable.	
28	Jacobs	Better Practice	When importing CAD terrain surfaces into SMS, consider using triangles from CAD and opening in SMS, then right clicking and converting CAD Faces to 2D Scatter Triangles. This will preserve the breaklines from CAD. WARNING - if you retriangulate the scatter surface the triangles are retriangulated without the CAD breaklines.	
29	Jacobs	Better Practice	When modeling 2D floodway encroachments look at depth to encroach into shallow areas, velocity to guide encroachment shape, unit discharge to avoid hotspots of deep/faster moving flow, and avoid blocking low spots without providing a way to drain them.	
30	Jacobs, CDOT R4	Better Practice	Run time of small riverine models (0.5 length, 300 ft wide) should take 10-min or less to run. Time step and mesh size should be adjusted accordingly to meet those run times.	
31	Jacobs, FHWA, CDOT R4	Standard Practice	Draw arcs (breaklines) at all major grade breaks including high points, and top and toe of slopes/walls to better define channel and structure geometries.	
32	Jacobs	Better Practice	Perform a sensitivity analysis on mesh element size.	
33	Jacobs	Better Practice	Perform a sensitivity analysis on Manning's n roughness values.	

34	Jacobs	Better Practice	Use spatially varied Manning's n values using aerial imagery to guide material type and shape.	
35	FHWA	Innovation Opportunity	Advanced Simulation - SRH-2D allows for running multiple simulations runs at once using a set of parameters to vary each model run. Running multiple simulations in this way can be used to either create alternate scenarios or it can be used to help calibrate the model.	https://www.xmswiki.com/wiki/SMS:SRH-2D_Advanced_Simulation

Agenda

2D Quick Check Training Course Agenda	
Day 1 (1-day)	Introductions & Objectives
	Demonstration: SH144, S Platte River
	Workshop #1: Familiarize with SMS capabilities
	Review 2D Modeling Best Practices
	Workshop #2: Apply Reviewer Best Practices
Day 2 (Half-day)	Workshop #3: Build a 2D Quick Check model
	Wrap-up & Questions

Innovation Functions	
Structure Updates	25
Channel/Bank Improvements	10
Scour Evaluation	18
Roadway Enhancements	6
Methodology Alternatives	18
Safety	14
Savings	17
Total =	108



Summary of 108 innovations and opportunities (tabular and pie chart) identified from 46 projects completed by the Colorado DOT and consulting partners from 2dQCs.