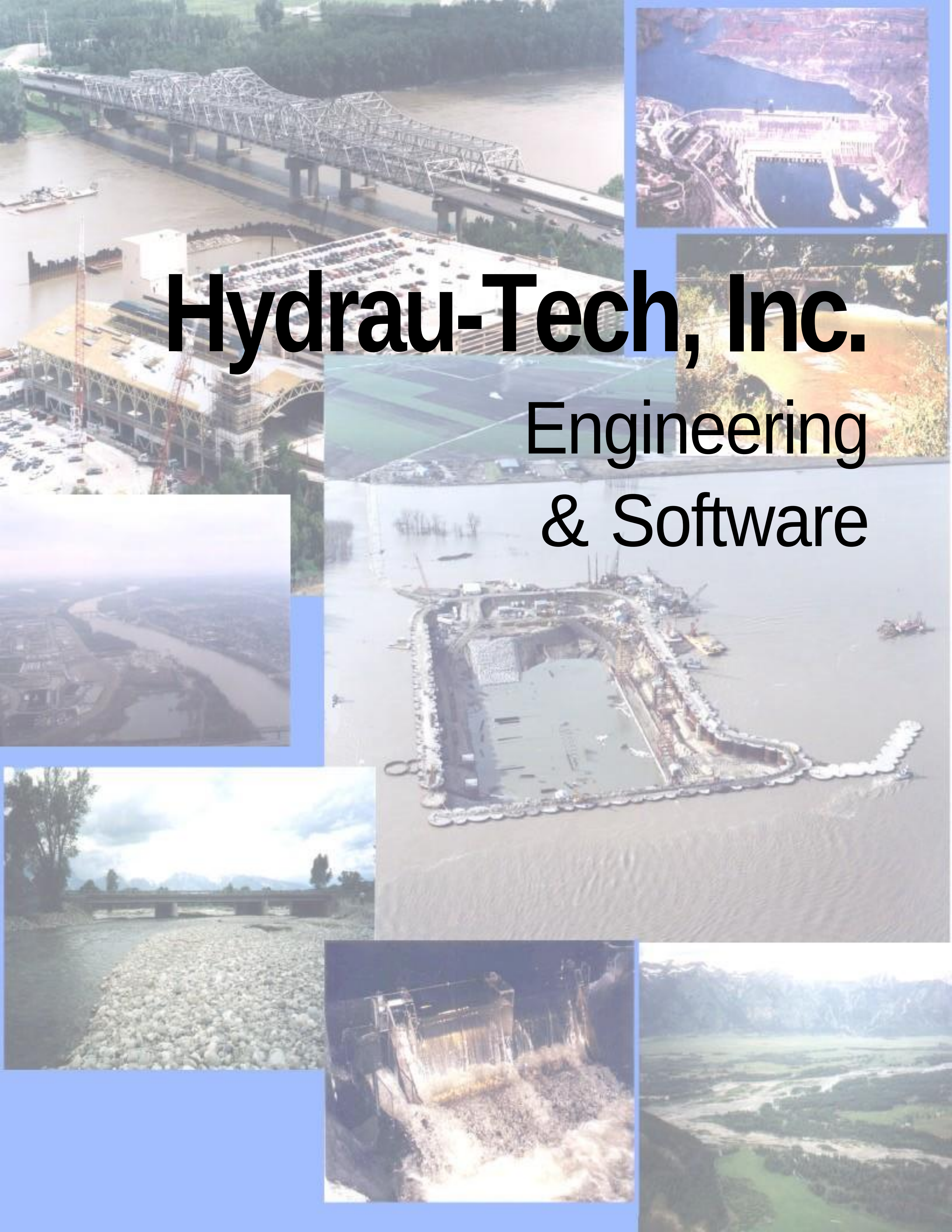
Hydrau-Tech, Inc.

Engineering & Software



HYDRAU-TECH, INC.

Hydrau-Tech, Inc. is an engineering consulting firm specializing since 1986 in open-channel hydraulics, watershed, river, and reservoir sedimentation, environmental river mechanics, river geomorphology and environmental management of sedimentation. Hydrau-Tech engineers have conducted extensive studies in pier and abutment scour, local scour due to reservoir power intakes, river sedimentation, and effects of sediment movement on hydraulic structures. They have also conducted basic research in measuring velocity and shear fields around bridge piers and abutments and channel contractions. In the field of numerical modeling, Hydrau-Tech engineers have developed the U.S. Bureau of Reclamation's GSTARS, and Federal Highway Administration's BRI-STARS models. They also have developed several well-known sediment-transport and bridge-scour relationships, and authored the *International Handbook of Reservoir Sedimentation*. Hydrau-Tech engineers have participated in numerous national and international projects, and are recognized for their knowledge and expertise in the areas of:

- Numerical modeling of rivers, reservoirs, and watersheds
- Experimental and numerical modeling of bridge scour and hydraulics
- Erosion and sedimentation
- Physical and numerical modeling of hydraulic structures
- Theoretical, experimental, and numerical Hydraulics
- Modeling of complex channel networks
- Hydraulics of dam failures and changes in channel morphology due to dam failures
- Hydrology
- River mechanics and river morphology
- Water-resource planning and management

Hydrau-Tech, Inc.'s past projects include software development, laboratory research and testing, physical modeling, mathematical modeling, and engineering analysis and application including:

- Laboratory study for effects of gradation and cohesion on scour
- Physical-model study of Rock Creek, Cresta and Poe Reservoir system
- BRI-STARS (Bridge Stream Tube Model for Alluvial River Simulations) enhancement and development
- Computer analysis of highway encroachments on mobile-boundary streams
- Implementation of lateral-inflow option to the GSTARS model
- Implementation of mass-wasting algorithms into BRI-STARS model
- Grand Teton National Park materials sources study
- Implementation of the sediment routing through the dendritic-channel-network option of the GSTARS model
- Application of watershed-sediment-routing model, HEC1WS, to Yazoo River Basin Bottomland Hardwoods project
- Assessment of the role of bottomland hardwoods in sediments and erosion control
- Plan of Action (POA) for scour-critical bridges

OUR CLIENTELE

The clientele of Hydrau-Tech, Inc. include:

- Colorado Department of Transportation
- U.S. Fish and Wildlife Service
- U.S. Federal Highway Administration
- National Academy of Sciences, Transportation Research Board
- U.S. Bureau of Reclamation
- U.S. Geological Survey
- U.S Army Corps of Engineers
- U.S. Environmental Protection Agency
- Pacific Gas & Electronic Company
- Private civil engineering consulting companies

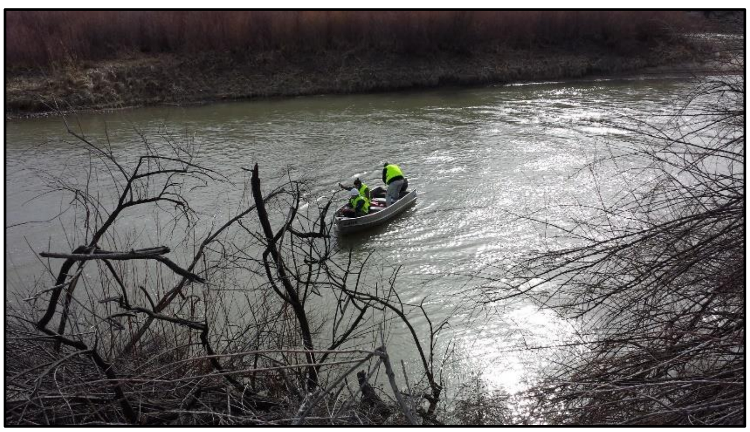
OUR SOFTWARE PRODUCTS

The commercial software products developed by Hydrau-Tech, Inc. are:

BRI-STARS	An enhanced version of the Federal Highway Administration's **BRI-STARS** (BRIdge Stream Tube model for Alluvial River Simulation).
GSTARS	A visually-interactive, enhanced version of the U.S. Bureau of Reclamation's **GSTARS** (Generalized Stream Tube model for Alluvial River Simulation).
SedWin	A visually-interactive **Sed**iment-transport model for **Win**dows, for computation of total and fractional sediment-transport capacities.
SedBase	A **Sed**iment-transport data**Base** for laboratory and field measurements, which contains complete records of flow, bed material, transported sediment, and size.
R-View	Channel **R**oughness **VIEW**er is based on U.S. Geological Survey measurements for selecting Manning's roughness values in natural rivers and man-made channels, using photographic information.

Capabilities of Hydrau-Tech, Inc.
Engineering Services

- Rapid flood-scour response
- Hydraulic surveying
- Underwater (bathometric) surveying
- Depth sounding
- Scour countermeasure testing and design
- Construction services
- Hydrologic investigative services
- Hydraulic investigative services
- Sedimentation modeling



2013 COLORADO FLOOD EMERGENCY HYDRAULIC RESPONSE

In September 2013, Colorado's Front Range experienced severe flooding which resulted in various high-flow-frequency events including a 500-year event. Hydrau-Tech, Inc. was selected as one of two companies to respond by inspecting and designing hydraulic-scour countermeasures for the Colorado Department of Transportation's (CDOT) failed and damaged bridges. During the flooding event, Hydrau-Tech engineers inspected bridges along Boulder Creek, Big Thompson River, South Platte River, St. Vrain Creek, and Cache la Poudre River, and advised structural engineers on the safety of bridges with respect to scour. Currently Hydrau-Tech, Inc. is reviewing over 700 bridges, and is in charge of providing scour-countermeasure design for over 100 bridges as well as performing construction supervision.

Boulder Creek at HW 36 during flood

Boulder Creek at HW 36 flows between NB and SB bridges

Big Thompson River at I-25, failed right abutment

Big Thompson River at I-25, flows attacking pier

Failed right abutment on HW 36 at Lyons

Bridge on HW 36 at Lyons after flood

After peak flows subsided, Hydrau-Tech, Inc. completed a detailed inspection for over 70 on-system bridges during the Rapid Field Assessment phase. Various bridge elements, including abutments, piers, grade-control structures, and highway-drainage structures were examined for failure, adequacy of riprap sizes, and foundation depths. Detailed descriptions of types of damage, levels of scour protection needed, and preliminary repair suggestions were provided. Maximum-capacity discharges were calculated, which were compared with calculated design discharges to determine if structures met CDOT criteria and specifications. Pertinent information gathered for this task included structure geometry, channel geometry, roughness values, watershed characteristics, and high-water marks.

Boulder Creek at US 287 after flooding

Boulder Creek at US 287, pier scour at spread footers

After the flooding occurred, Hydrau-Tech engineers were involved in the process of categorizing bridges impacted by flooding across the state. Determinations were made for level of damage sustained during the event, extent of necessary repairs, and level of analysis necessary to implement those repairs. Bridges were classified into four categories:

- Category 1 - No Action: reported scour will not adversely affect bridge structure.
- Category 2 - Minor Scour: standard or simplified design can be used for scour repairs.
- Category 3 - Moderate Scour: some level of hydraulic survey and design is required for the repair.
- Category 4 - Extensive Scour: full site survey and hydraulic design are required for the repair.

The classification process involved numerous site visits focusing on assessing the severity of the damages as well as the complexity of the local stream system and ecology. Hydrau-Tech, Inc. used the classification information in the design of appropriate countermeasures.

BRIDGE CATEGORY EXAMPLES

CATEGORY 1: NO ACTION

South Platte River at SH 287 44, minimal flood damage

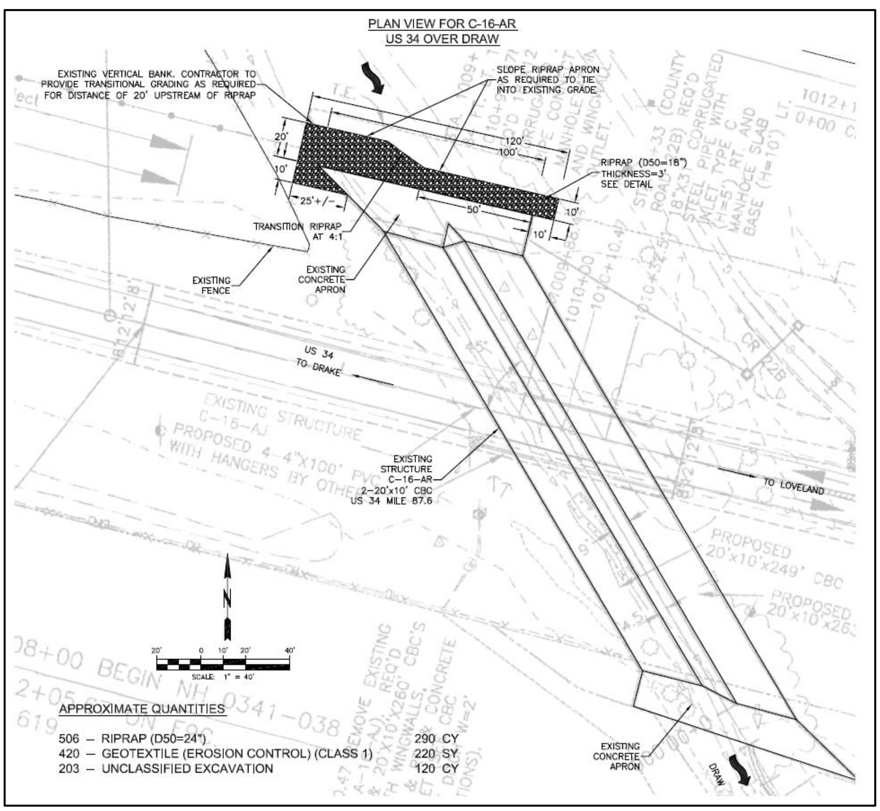
CATEGORY 2: MINOR SCOUR

C-16-AR over Draw

Category 2 bridges experienced minor scour and did not require survey. Minor damage at these sites was typically addressed with standard or simplified scour-repair designs. In the case of C-16-AR, the upstream scour hole was filled, regraded, and protected with 18-inch riprap.

Pre-Construction

Post-Construction



C-16-AR Countermeasure Design

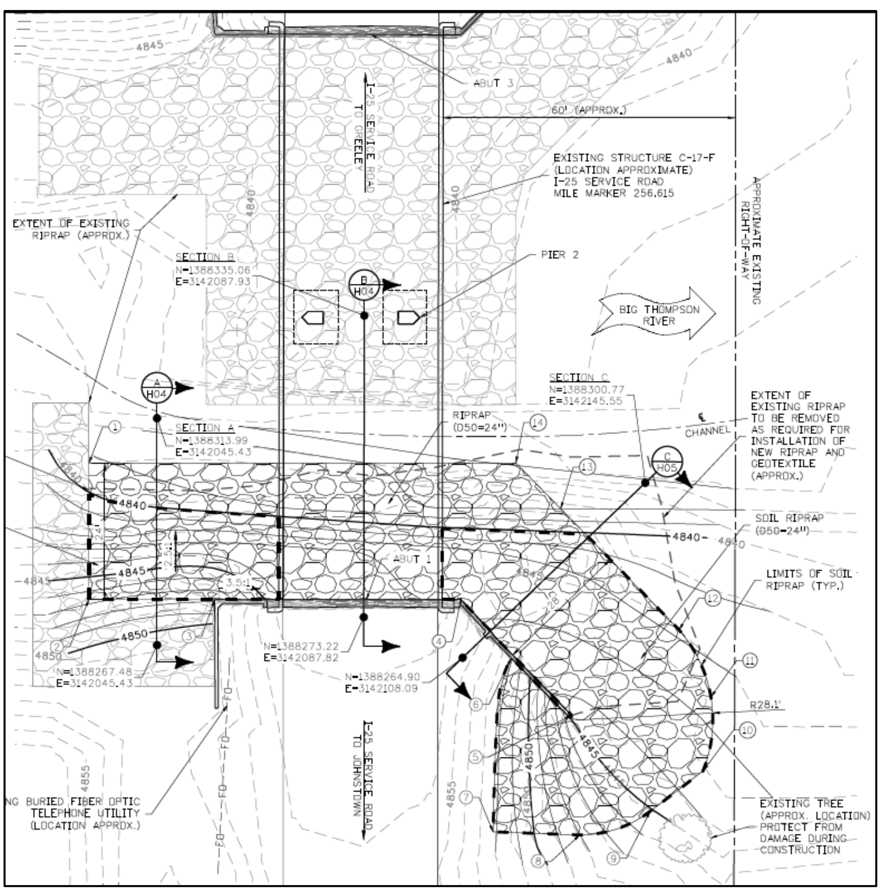
CATEGROY 3: MODERATE SCOUR

C-17-F over Big Thompson River

Category 3 bridges experienced moderate scour and required hydraulic survey and analysis prior to design of countermeasures. At structure C-17-F, the results of the hydraulic survey and analysis were used to design armoring countermeasures to repair severe scour and prevent future contraction scour, abutment and pier scour, and channel degradation.

Pre-Construction

Post-Construction



C-17-F Countermeasure Design

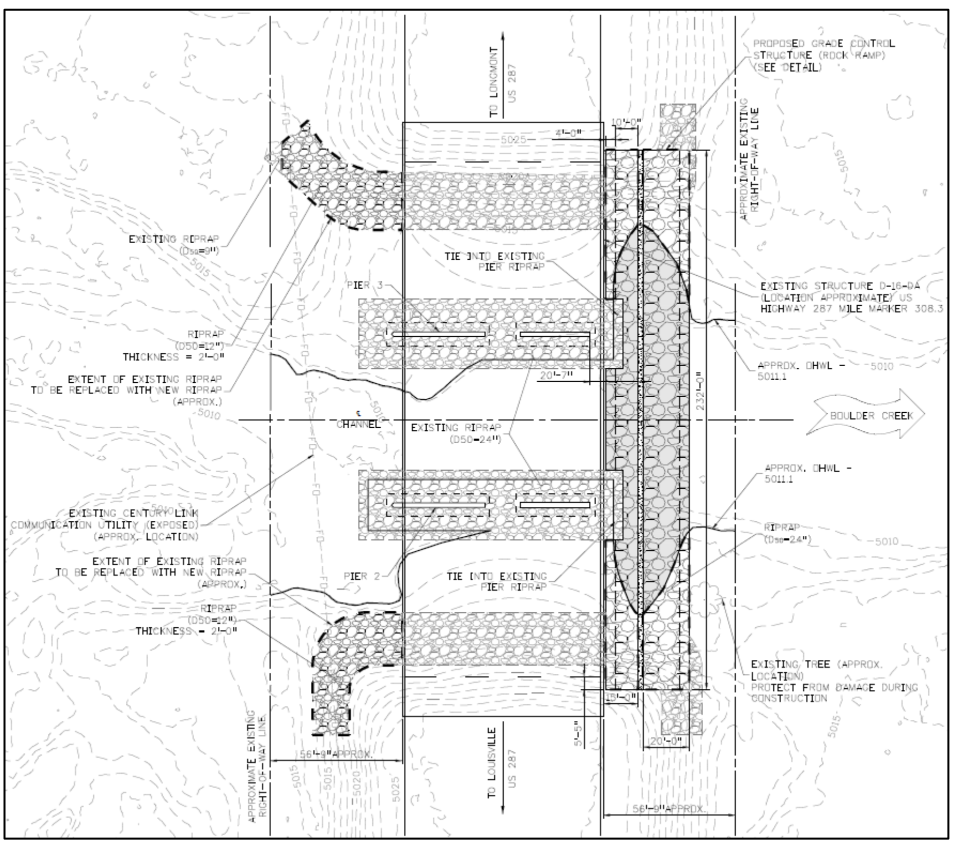
CATEGORY 4: EXTENSIVE SCOUR

D-16-DA over Boulder Creek

Category 4 bridges experienced extensive scour and required either a PLS survey or collection of LIDAR data prior to entering the design phase. Damages at these sites often required specially-designed countermeasures. In the case of D-16-DA, an armored grade-control structure was installed alongside sections of supplementary riprap where necessary.

During Construction

Post-Construction



D-16-DA Countermeasure Design

C-17-N over Little Thompson River – Scour at left embankment and downcutting between piers

E-16-BC over Coal Creek – Significant scour hole downstream and from right abutment up to roadway

C-17-N over Little Thompson River – Channel and left embankment scour upstream of bridge

E-16-BC over Coal Creek – Scour hole from downstream right abutment to roadway

C-17-N over Little Thompson River – Exposed pier cap due to channel degradation and scour

E-16-BC over Coal Creek – Scour damage to adjoining bike path


E-16-HB over Coal Creek - Scour at downstream right abutment


C-17-B over South Platte River – High flows and sediment discharges have changed channel morphology


E-16-HB over Coal Creek - Scour at bridge outlet


C-17-B over South Platte River – Exposed left abutment piles


E-16-HB over Coal Creek – Downstream right abutment scour and undermining of structure


C-17-B over South Platte River – Debris accumulation up to low girder


A-17-AC over Lone Tree Creek – Abutment riprap loss


A-17-AC over Lone Tree Creek – Scour hole at left pier


A-17-AC over Lone Tree Creek – Debris accumulation at pier


C-16-AF over Buckingham Ditch – Scour at downstream left abutment


C-16-AF over Buckingham Ditch – The ditch berm or levee was washed out from Big Thompson overtopping


C-16-AF over Buckingham Ditch - Scour at downstream left abutment


D-16-DA over Boulder Creek – Upstream face of bridge


C-16-DK over Little Thompson River – Downstream channel scouring


D-16-DA over Boulder Creek – Pier caps exposed beneath water surface


C-16-DK over Little Thompson River – Scour at right abutment


D-16-DA over Boulder Creek – Scouring of channel bank


C-16-DK over Little Thompson River – Debris accumulation above low girder

C-17-BL over Big Thompson River – Channel widening and downcutting through bridge section

C-17-C over Little Thompson River – Right abutment scour

C-17-BL over Big Thompson River – Loss of defined channel downstream of bridge due to contraction scour

C-17-C over Little Thompson River – Channel and embankment scour leading to left abutment

C-17-BL over Big Thompson River – Riprap loss at right abutment

C-17-C over Little Thompson River – Left abutment and embankment scour downstream

C-17-CZ over Draw – Center bay experienced several feet of channel downcutting

D-15-X over Left Hand Creek – Culvert inlet with debris and cobble accumulation

C-17-CZ over Draw – Bank scour on approach to right abutment

D-15-X over Left Hand Creek – Culvert outlet and abutment s show significant scour and undermining

C-17-CZ over Draw –Bridge outlet showing steep gradient and channel downcutting

D-15-X over Left Hand Creek – Downstream embankment and channel failure due to contraction scour

C-17-Z over Big Thompson River –Downstream left abutment scour

C-18-AG over South Platte River – Channel bank scour

C-17-Z over Big Thompson River – Exposed left abutment piles

C-18-AG over South Platte River – Scour hole in between piers

C-17-Z over Big Thompson River - Scour of right emnamkment downstream

C-18-AG over South Platte River – Debris left from high water

INSPECTION ITEMIZATION

Inspection Priority	Assignment	Prelim Scour Inspection Completed Date	**Repair Categorization -** **1 - No Action. No Repair Required.** **2 - Low - Standard scour protection detail acceptable** **3 - Medium - Some level of hydraulic survey and site specific design** **4 - High - Complete site survey and design**	Reinspect at Lower Water?	Damage Type	Suggested Repair	Structure ID	Structure ID	Feature Carried	Lat	Feature Crossed	Feature Carried	Location	Route	Mile Post	Lat	Long
1	Hydrau Tech	9/24/2013	3	N	Scour at pier 2. Abutment toes scoured. Downstream embankment riprap missing.	Riprap replenishment and installation.	9/18/13 14:16	A-17-AC	1	Open	LONE TREE CREEK	I 25 ML NBND	3.8 MI S. OF WYOMING S.L.	025A	295.038	40.9459857	-104.925425
1	Hydrau Tech	9/24/2013	3	N	Scour at pier 3. Abutment toe mildly damaged.	Riprap replenishment and extention along embankments. Riprap at pier.		A-17-AD	1	Open	LONE TREE CREEK	I 25 ML SBND	3.7 MI S OF WYOMING S.L.	025A	295.039	40.9461587	-104.925723
2	Hydrau Tech	9/27/2013	2	Y	Needs reinspected, still experiencing high water, right embankment shows loss of riprap		9/20/13 13:12	A-28-M	1	Open	SOUTH PLATTE RIVER	US 385 ML	0.8 MI N OF I 76	385D	309.919	40.9785733	-102.255106
2	Hydrau Tech	9/26/2013	2	Y	Riprap missing on both embankments and on right abutment, left pier underwater		9/20/13 18:36	B-16-D	1	Open	CACHE LA POUDRE RIVER	SH 14 ML	1 MI E OF JCT US 287	014C	135.909	40.5813957	-105.058667
1	Hydrau Tech	9/26/2013	2	Y	Piers are under water, riprap missing along both abutments and embankments		9/18/13 15:34	B-17-BB	1	Open	CACHE LA POUDRE RIVER	I 25 ML SBND	3.5 MI S OF JCT SH 14	025A	265.79	40.530903	-104.993138
1	Hydrau Tech	9/26/2013	2	Y	Piers are under water, riprap missing along both abutments and embankments		9/18/13 11:40	B-17-DI	1	Open	CACHE LA POUDRE RIVER	I 25 ML NBND	8.5 MI N OF JCT US 34	025A	265.789	40.5308665	-104.993472
	Hydrau Tech	10/2/2013	2	Y	Embankment damage upstream. Missing riprap on both embankments.	Both embankments upstream and downstream need riprap installed. Upstream left embankment needs repair.	9/22/13 5:48	C-16-AE	1	Open	BIG THOMPSON RIVER	US 34 ML	1 MI W OF LOVELAND	034A	86.931	40.4107671	-105.166085
	Hydrau Tech	10/2/2013	3	Y	Downstream embankment gone. Both upstream and downstream wingwall foundations exposed. Downstream left wingwall has scour behind it.	Upstream left embankment needs standard riprap design. Downstream left wingwall needs filled in behind and riprap installed. Left embankment levy downstream needs to be redone and protected with riprap. Wingwall foundations need filled in and riprap installed.	9/22/13 5:51	C-16-AF	1	Open	BUCKINGHAM DITCH	US 34 ML	2 MI WEST OF LOVELAND	034A	86.176	40.4190882	-105.177505
	Hydrau Tech	10/2/2013	3	Y	Left abutment washed out. Piles exposed 3-4 feet. No riprap under structure. No riprap protection on upstream and downstream embankments of right abutment. Large headcut moving upstream close to left abutment. Check at lower flow to see scour damage.	Riprap left abutment. Debris removal. Re-cover articulating concrete blocks on right abutment with soil. Place riprap upstream and downstream along the embankments on the right abutment.	9/22/13 5:56	C-16-DA	1	Closed	BIG THOMPSON RIVER	US 34 ML	3 MI W OF LOVELAND	034A	85.133	40.415097	-105.195485
1	Hydrau Tech	9/25/2013	2	Y	ACB's exposed on embankment and abutment slopes. Upstream right embankment damaged.	Upstream right embankment repair and riprap installation.	9/17/13 12:12	C-16-DD	1	Closed	BIG THOMPSON RIVER	US 34 ML	2 MI W OF LOVELAND	034A	86.026	40.4187403	-105.180248
1n	Hydrau Tech	9/25/2013	3	N	Abutment slopes damaged and missing riprap. Both u/s and d/s embankments damaged and missing riprap.	Repair of abutment and embankment slopes and riprap installation	9/19/13 14:49	C-16-DK	1	Open	LITTLE THOMPSON RIVER	US 287 ML	5.1 MI N OF JCT SH 66	287C	323.503	40.2773378	-105.102553
1	Hydrau Tech	9/25/2013	2	Y	Piers under water. Embankments behind abutment walls damaged.	Embankment repair and riprap installation.	9/19/13 12:39	C-16-H	1	Closed	BIG THOMPSON RIVER	US 287 ML	0.4 MI N OF JCT SH 402	287C	332.295	40.3832902	-105.07336
1	Hydrau Tech	9/24/2013	4	N			9/19/13 14:16	C-17-A	1	Open	LITTLE THOMPSON RIVER	I 25 ML SBND	0.4 MI SO OF JCT SH 56	025A	249.789	40.3010546	-104.980357
	Hydrau Tech		4	Y	Left abutment under structure missing riprap. Piles exposed 3 feet. Piers underwater so scour depth is unkown.	Riprap left abutment to cover piles. Remove debris from right abutment bay. Minor riprap installation at right abutment. Remove debris from right flood plain bays (6 or so).	9/22/13 13:59	C-17-B	1	Open	SOUTH PLATTE RIVER	SH 60 ML	3.7 MI E OF JCT SH 257	060B	15.475	40.319366	-104.811123
1	Hydrau Tech	9/24/2013	3	Y	Embankment failure on right embankment. Unkown pier scour due to high flow.		9/19/13 13:39	C-17-BL	1	Open	BIG THOMPSON RIVER	I 25 ML SBND	0.7 MI SO OF JCT US 34	025A	256.549	40.3972586	-104.993491
1	Hydrau Tech	9/24/2013	3	Y	Unknown due to high flow.		9/19/13 13:31	C-17-BM	1	Open	BIG THOMPSON RIVER	I 25 ML NBND	1.3 MI N OF JCT SH 402	025A	256.548	40.3972586	-104.993179
	Hydrau Tech	10/2/2013	3	Y	Right abutment piles exposed. Upstream embankment at right abutment is failing. Piles exposed at left abutment.	Decrease slope of riprap on right abutment. Riprap upstream and downstream of right abutment. Riprap left abutment and upstream and downstream embankments.	9/22/13 10:31	C-17-C	1	Open	LITTLE THOMPSON RIVER	SH 60 ML	5.8 MI E OF JCT I 25	060B	11.662	40.3330764	-104.870905

Inspection Priority	Assignment	Prelim Scour Inspection Completed Date	Repair Categorization - 1 - No Action. No Repair Required. 2 - Low - Standard scour protection detail acceptable 3 - Medium - Some level of hydraulic survey and site specific design 4 - High - Complete site survey and design	Reinspect at Lower Water?	Damage Type	Suggested Repair	Structure ID	Structure ID	Feature Carried	Lat	Feature Crossed	Feature Carried	Location	Route	Mile Post	Lat	Long
	Hydrau Tech	10/2/2013	3	N	Right embankment failure. Piles exposed on both abutments 1 foot. Channel downcutting.	Abutment slope and embankment repair upstream and downstream. Riprap installation on abutments, embankments upstream and downstream, and piers.	9/21/13 11:48	C-17-CZ	1	Open	DRAW	SH 257 ML	2.2 MI NO OF JCT US 34	257A	7.607	40.436836	-104.886754
1	Hydrau Tech	9/24/2013	3	Y	Unknown due to high flow.		9/21/13 16:03	C-17-F	1	Open	BIG THOMPSON RIVER SR	I 25 SERVICE RD	1.3 MI N OF JCT SH 402	025A	256.615	40.3976013	-104.993193
1	Hydrau Tech	9/24/2013	4	N			9/19/13 18:27	C-17-FS	1	Open	LITTLE THOMPSON RIVER SR	I 25 SERVICE RD	6.7 MI NO OF JCT SH 56	025A	249.847	40.3010437	-104.979727
1	Hydrau Tech	9/24/2013	4	Y			9/19/13 14:19	C-17-N	1	Open	LITTLE THOMPSON RIVER	I 25 ML NBND	6.7 MI N OF JCT SH 66	025A	249.788	40.3010641	-104.980092
1	Hydrau Tech	9/25/2013	2	Y	Abutments scoured out. Riprap has been pushed under abutment but at too steep of a slope. Downstream embankment riprap missing. Upstream right embankment eroded away and missing riprap.	Repair of abutment and embankment slopes and riprap installation. Pier protection possibility.	9/26/13 15:09	C-17-Y	1	Closed	LITTLE THOMPSON RIVER	SH 257 ML	0.2 MI NO OF JCT SH 60	257A	0.167	40.3351182	-104.867685
	Hydrau Tech	10/2/2013	3	Y	Left abutment piles exposed 1-2 feet. Right abutment toe scour. Downstream right embankment missing riprap. Right abutment needs filled in behind concrete pad around piles.	Lower riprap slope at left abutment and add more to cover piles. Downstream right embankment needs riprap.	9/26/13 15:12	C-17-Z	1	Closed	BIG THOMPSON RIVER	SH 257 ML	0.8 MI NO OF JCT SH 60	257A	0.762	40.3439678	-104.867854
2	Hydrau Tech	9/26/2013	3	Y	Right Abutment Scour, Upstream Right embankment damage, piers underneath high flow		9/20/13 15:54	C-18-AG	1	Open	SOUTH PLATTE RIVER	US 85 ML SBND	S. EDGE OF EVANS	085C	263.657	40.3657715	-104.696493
1	Hydrau Tech	9/25/2013	3	Y	Abutment damage and missing embankment on right abutment. Piers underwater. Piles exposed on d/s end of left abutment.	Abutment and embankment repair. Riprap installation	9/17/13 14:18	C-18-J	1	Closed	SOUTH PLATTE RIVER	US 34 BUSINESS	2.9 MI E OF JCT US 85-C	034D	14.109	40.3967196	-104.638707
	Hydrau Tech	10/3/2013	3	Y	Embankments damaged upstream and downstream. Right abutment is sticking out 10-15 feet with minimal protection.	Embankment repair and riprap installation on both sides. Riprap right abutment at upstream.	9/27/13 10:23	D-15-A	1	Open	NORTH ST VRAIN CREEK	SH 7 ML	IN LYONS	007A	32.973	40.2227321	-105.27165
	Hydrau Tech	10/3/2013	2	N	Riprap sparce on both abutments.	Riprap both abutments and upstream and downstream embankments. Riprap pier. Debris removal downstream.	9/21/13 13:20	D-15-B	1	Open	FOUR MILE CANYON CREEK	US 36 ML	28th ST in BOULDER	036B	34.314	40.0463759	-105.258522
	Hydrau Tech	10/3/2013	2	Y	Unkown scour along abutments due to high flow. Embankment damage downstream end on both sides.	Downstream embankments need repair and riprap installation. Upstream right abutment needs riprap replenishment and extension	9/27/13 10:08	D-15-BA	1	Open	NORTH ST VRAIN CREEK	US 36 ML	IN LYONS	036B	19.796	40.229438	-105.276143
	Hydrau Tech	10/3/2013	3	Y	Major embankment damage downstream of both abutments. Lots of debris downstream. Scour at outlet.	Debris removal. Repair downstream embankments. Riprap both upstream and downstream embankments.	9/21/13 13:31	D-15-X	1	Closed	LEFT HAND CREEK	US 36 ML	6.2 MI SO OF JCT SH 66	036B	27.961	40.1299319	-105.28226
	Hydrau Tech	10/3/2013	2	Y	Scour at outlet. Wingwall and structure foundation downstream exposed by about 2 feet. Reinspect for undermining at lower flow. Flow is attacking left embankment downstream directly with very little protection.	Riprap downstream left embankment and along the structure foundations and wingwalls. Riprap upstream right embankment and remove debris from right bay and channel.	9/22/13 13:03	D-16-BW	1	Open	DRAW	SH 7 ML	4.6 MI E OF ARAPAHOE RD	007C	57.106	40.0146338	-105.171597
	Hydrau Tech	10/3/2013	2	Y	Right pier pile caps exposed. Depth unkown due to flow.	Fill in scour at pier and riprap. Debris Removal.	9/25/13 16:01	D-16-DA	1	Open	BOULDER CREEK	US 287 ML	3 MI N OF JCT SH 7	287C	308.338	40.0591613	-105.102678
	Hydrau Tech	10/3/2013	2	Y	Scour hole at pier. Flow too high to measure depth.	Extend riprap upstream and downstream of both abutments and bikepath. Debris Removal.	9/22/13 14:52	D-16-DM	1	Open	COAL CREEK	SH 7 ML	1.7 MI E OF JCT US 287	007D	64.232	40.0002738	-105.058768
	Hydrau Tech	10/3/2013	3	N	Upstream headwall has scour holes behind it. Downstream right wingwall failed. Large scour hole downstream of structure. Left bank failure. Right bank failure. Right side roadway embankment downstream failed.	Fix wingwall and both embankments. Riprap embankments from abutments and extend downstream. Fill in scour hole and riprap outlet in channel.	9/22/13 17:12	E-16-BC	1	Open	COAL CREEK	SH 42 ML	3.3 MI SE OF JCT SH 7	042A	3.21	39.9725646	-105.121317
	Hydrau Tech	10/3/2013	3	N	Small scour hole upstream of right abutment wingwall. Bank failure on both sides downstream. Downstream end of culvert is undermined and sticks out about 12 feet.	Fill in upstream right wingwall scour hole. Repair downstream embankments and riprap both sides. Fill in scour hole at outlet and under structure.	9/26/13 13:59	E-16-HB	1	Open	COAL CREEK	SH 128 ML	0.4 MI E OF JCT SH 93	128A	0.4	39.9245718	-105.227754

PLANS OF ACTION FOR SCOUR-CRITICAL BRIDGES

In 1991 the Federal Highway Administration (FHWA) required all states to provide Plans of Action (POA) for scour-critical bridges. A nationwide mandate from FHWA required CDOT to evaluate and develop POA reports for each of 243 bridges identified as scour-critical, and structures with unknown foundations. CDOT created a program and multi-disciplinary POA team to address these bridges. As a part of this effort, Hydrau-Tech, Inc. was responsible over a 3-year period for conducting 135 POA studies which included reports for each structure. As of September, 2013, Hydrau-Tech, Inc. has completed 113 reports for scour-critical bridges, and 19 reports for structures with unknown foundations.

In the following pages summaries of several of these reports are presented. A full set of reports is available on Hydrau-Tech, Inc.'s FTP website at ftp://ftp.hydrau-tech.com/CDOT/. To access these reports online, select an appropriate POA report directory based on the fiscal year, and select the report of interest.

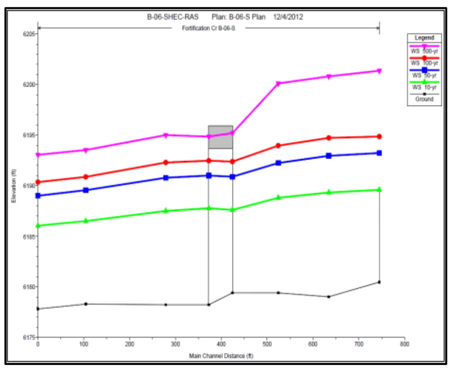
HIGHWAY 40 BRIDGE B-06-S OVER FORTIFICATION CREEK
CRAIG, COLORADO

Bridge B-06-S is located in Moffat County on the U.S. Highway 40 mainline where its crosses Fortification Creek. Figure 1 shows Bridge B-06-S over Fortification Creek.

Hydrau-Tech, Inc. began the POA study of Bridge B-06-S by collecting site and structure information including hydrologic characteristics, GIS information and original bridge construction plans. Using this information, regional regression equations resulted in a 500-year flood discharge of 7510 cfs (cubic feet per second). After completing a survey of the reach upstream and downstream of the structure and analysis of sediment size, a HEC-RAS hydraulic model was developed. The model was used to estimate hydraulic conditions during the 500-year flow, including discharge distributions, velocity distributions, and water-surface profiles. Figure 2 shows the water-surface profile produced by the HEC-RAS hydraulic model. Figure 3 shows the reach-geometry plot produced by HEC-RAS.

Using results from hydraulic modeling, theoretical-scour estimates were calculated using FHWA's HEC-18 scour equations. AutoCAD drawings were produced with adjusted datum elevations and theoretical-scour lines in order to determine the stability of the structure under flood-scour conditions. Figure 4 shows a completed theoretical-scour plot created with AutoCAD, which shows foundation elevations and potential scour.

Figure 1. Bridge B-06-S over Fortification Creek



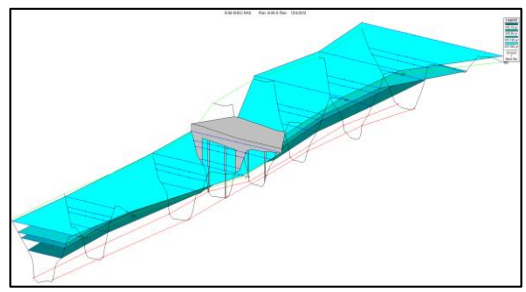


Figure 2 (Left). Water-surface profile showing the 10-, 50-, 100- and 500-year flows; **Figure 3** (Right). 3D Plot of the reach around structure B-06-S

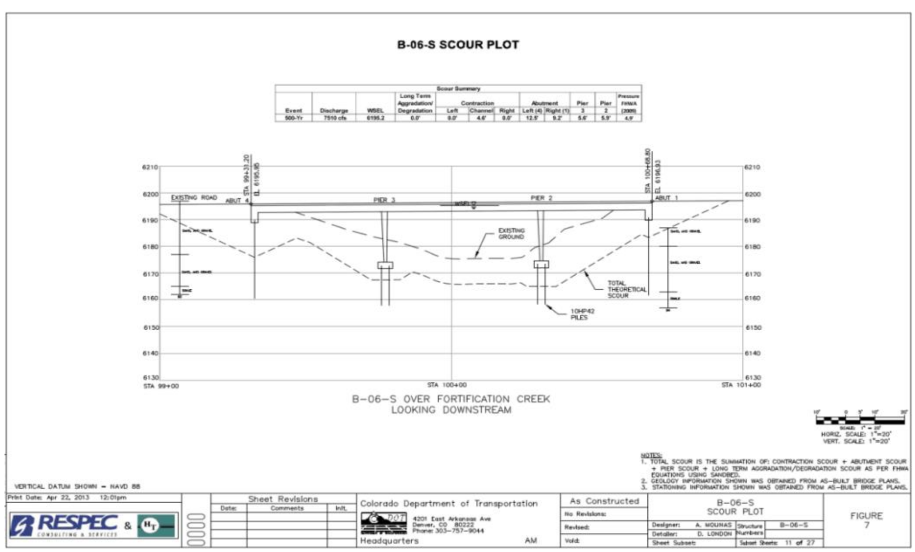


Figure 4. Scour plot generated in AutoCAD showing bridge geometry, foundation elevations, sediment boring-hole results and theoretical scour

Countermeasures were designed by Hydrau-Tech, Inc. based on theoretical scour and current site conditions, such as foundation depth and existing structure protection. Riprap was chosen as the hydraulic-scour countermeasure. Pier and abutment riprap sizing were determined using FHWA's equations. Based on theoretical velocities, riprap with a median grain-size diameter of 2.0 feet was used in the design of the abutment and pier protection. Using guidelines in HEC-23 for design of riprap protection, Hydrau-Tech, Inc. developed preliminary riprap countermeasures at critical locations on the bridge (right abutment and pier 2). Figure 5 is an aerial image of structure B-06-S with the recommended scour countermeasures. Figure 6 is a cross-sectional view of the structure with recommended scour-countermeasures and appropriate geometry. As a part of analysis, cost estimates for alternate countermeasures were created for comparison.

Figure 5. Plan view of Bridge B-06-S with recommended hydraulic-scour countermeasure locations

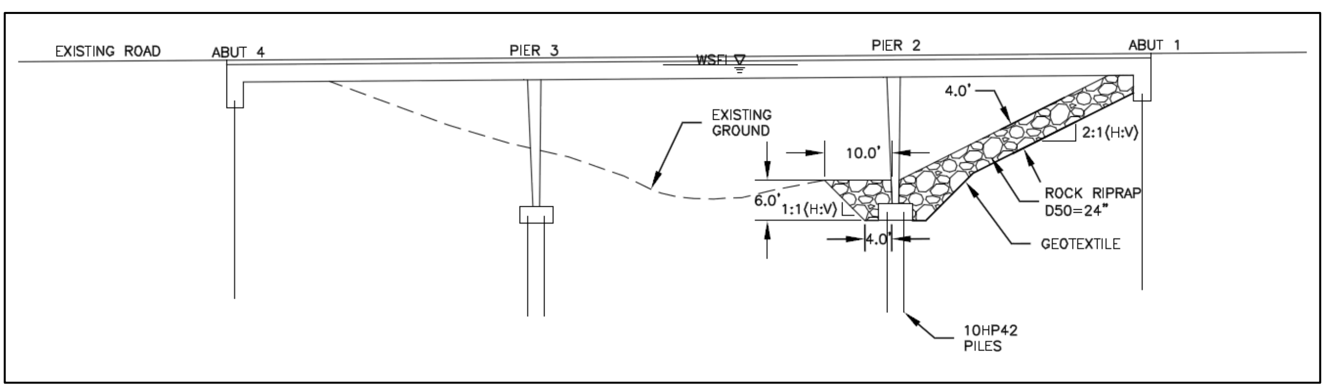


Figure 6. Cross-sectional view of Bridge B-06-S with recommended hydraulic-scour countermeasures

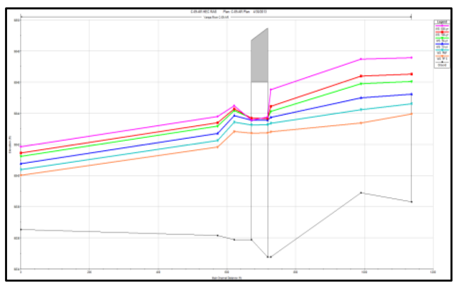
STATE HIGHWAY 131 BRIDGE C-09-AR OVER THE YAMPA RIVER, COLORADO

Bridge C-09-AR is located in Routt County where the State Highway 131 mainline crosses the Yampa River. Figure 1 shows Bridge C-09-AR over the Yampa River.

Hydrau-Tech, Inc. began the POA study of Bridge C-09-AR by collecting site and structure information including hydrologic characteristics, GIS information, and original bridge construction plans. Using this information, regional regression equations resulted in a 500-year flood discharge of 5.650 cfs. After completing a survey of the reach upstream and downstream of the structure and analysis of sediment size, a HEC-RAS hydraulic model was developed. The model was used to estimate hydraulic conditions during the 500-year flow, including discharge distributions, velocity distributions, and water-surface profiles. Figure 2 shows the water-surface profile produced by the HEC-RAS hydraulic model. Figure 3 shows the reach-geometry plot produced by HEC-RAS.

Using results from hydraulic modeling, theoretical-scour estimates were calculated with FHWA's HEC-18 scour equations. AutoCAD drawings were produced with adjusted datum elevations and theoretical-scour lines in order to determine the stability of the structure under flood-scour conditions. Figure 4 is a theoretical-scour plot which shows foundation elevations and potential scour.

Figure 3. Bridge C-09-AR over Fortification Creek



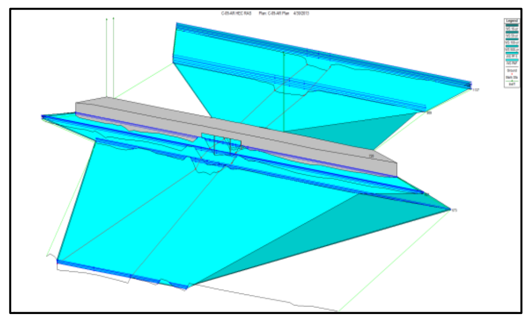


Figure 4 (Left). Water surface profile showing the 10-, 50-, 100- and 500-year flows; Figure 3 (Right). 3D-plot of the reach around structure C-09-AR

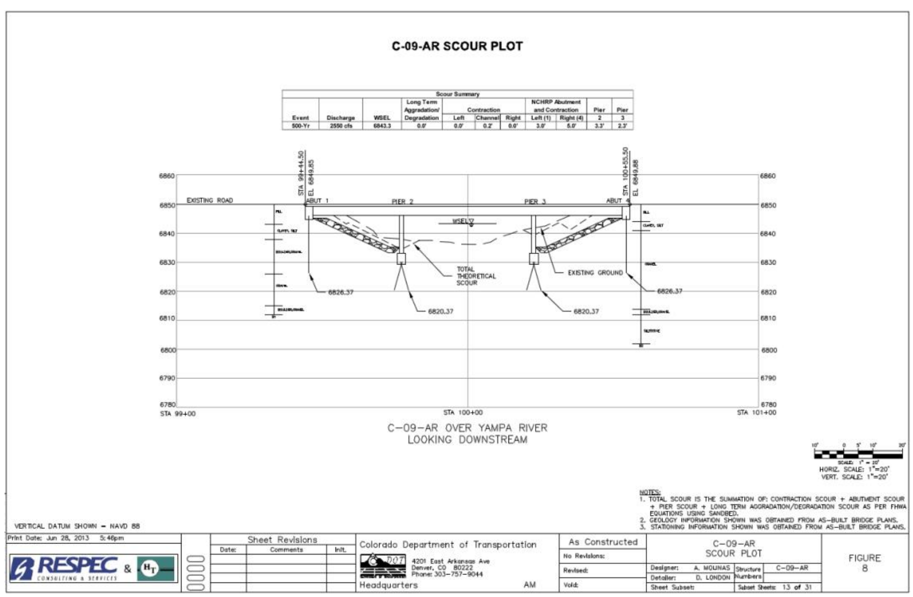


Figure 4. Scour plot generated in AutoCAD showing bridge geometry, foundation elevations, sediment boring-hole results and theoretical scour

Countermeasures were designed by Hydrau-Tech, Inc. based on theoretical scour and current site conditions, such as foundation depths and existing structure protection. Riprap was chosen as the hydraulic-scour countermeasure. Pier and abutment riprap sizing were determined using FHWA's equations. Based on theoretical velocities, riprap with a median-grain size diameter of 2.0 feet was included in the design of the abutment and pier protection. Using guidelines in HEC-23 for design of riprap protection, Hydrau-Tech, Inc. developed preliminary riprap-countermeasures at critical locations on the bridge (right abutment and pier 2). Figure 5 shows an aerial image of structure C-09-AR with the recommended scour countermeasures. Figure 6 is a cross-sectional view of the structure with recommended scour countermeasures and appropriate geometry. As a part of analysis, cost estimates for alternate countermeasures were created for comparison.

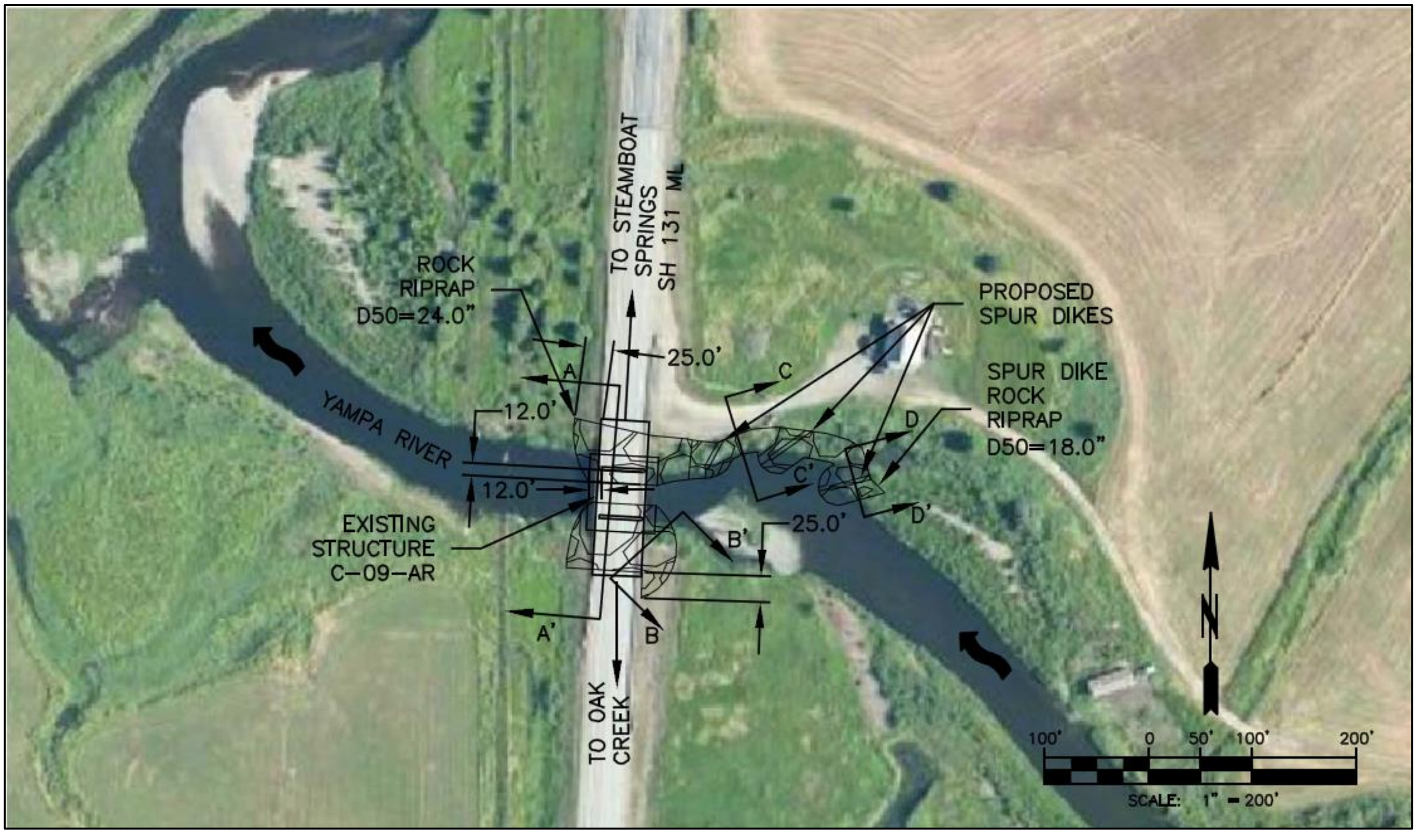


Figure 5. Plan view of Bridge C-09-AR with recommended hydraulic-scour countermeasure locations

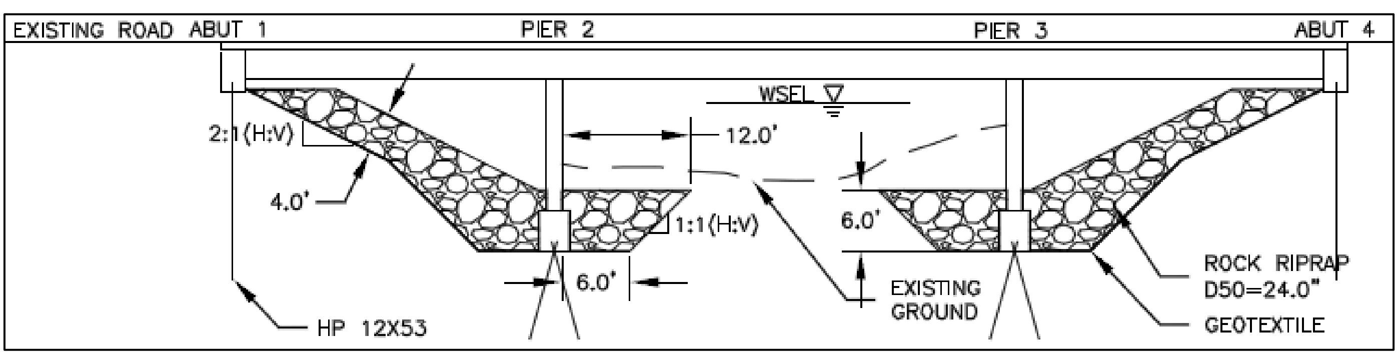


Figure 6. Cross-sectional view of Bridge C-09-AR with recommended hydraulic-scour countermeasures

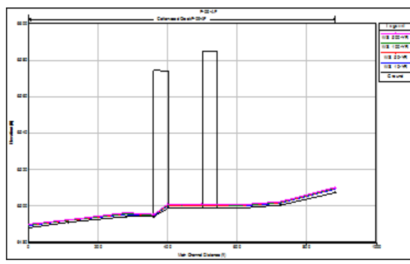
INTERSTATE 70 BRIDGE F-09-AF OVER COTTONWOOD CREEK, COLORADO

Bridge F-09-AF is located in Moffat County on the Interstate 70 mainline where it crosses Cottonwood Creek. Figure 1 shows Bridge F-09-AF over Cottonwood Creek.

Hydrau-Tech, Inc. began the POA study of Bridge F-09-AF by collecting site and structure information including hydrologic characteristics, GIS information, and original bridge construction plans. Using this information, regional regression equations resulted in a 500-year flood discharge of 288 cfs. After completing a survey of the reach upstream and downstream of the structure and analysis of sediment size, a HEC-RAS hydraulic model was developed. This model was used to estimate hydraulic conditions during the 500-year flow, including discharge distributions, velocity distributions, and water-surface profiles. Figure 2 shows the water-surface profile produced by the HEC-RAS hydraulic model. Figure 3 shows the reach-geometry plot produced by HEC-RAS.

Using results from hydraulic modeling, theoretical-scour estimates were calculated with FHWA's HEC-18 scour equations. AutoCAD drawings were produced with adjusted datum elevations and theoretical-scour lines in order to determine the stability of the structure under flood-scour conditions. Figure 4 shows a completed theoretical-scour plot crested with AutoCAD, showing foundation elevations and potential scour.

Figure 5. Bridge F-09-AF over Cottonwood Creek



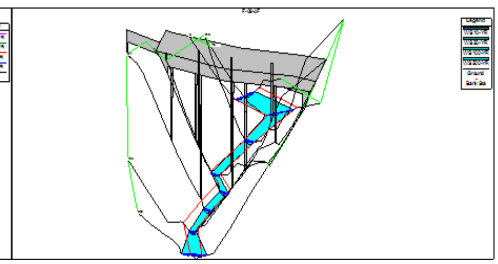


Figure 6 (Left). Water-surface profile showing the 10-, 50-, 100- and 500-year flows; Figure 3 (Right). 3D plot of the reach around structure F-09-AF

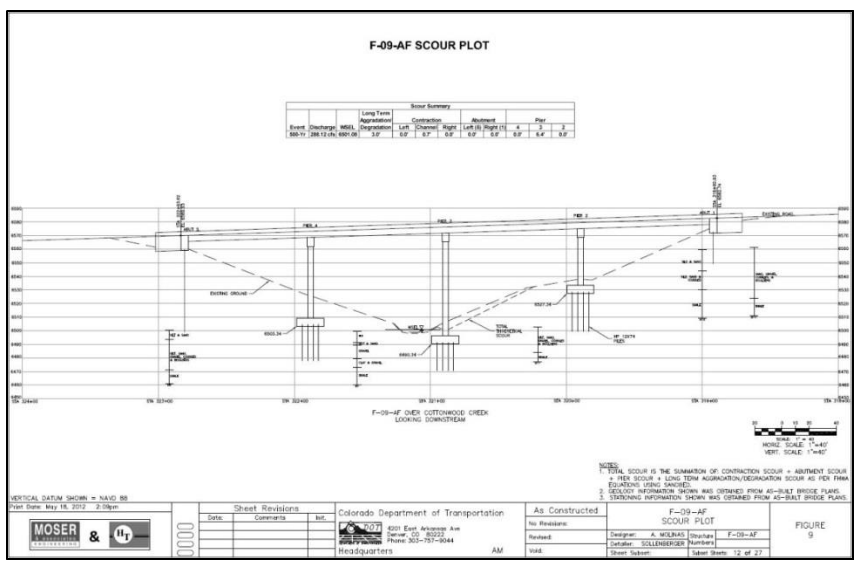


Figure 4. Scour plot generated in AutoCAD showing bridge geometry, foundation elevations, sediment bore-hole results and theoretical scour

Countermeasures were designed by Hydrau-Tech, Inc. based on theoretical scour and current site conditions, such as foundation depth and existing structure protection. Riprap was chosen as the hydraulic-scour countermeasure. Pier and abutment riprap sizing were determined using FHWA's equations. Based on theoretical velocities, riprap with a median grain-size diameter of 1.0 feet was included in the design of the abutment and pier protection. Using guidelines in HEC-23 for design of riprap protection, Hydrau-Tech, Inc. developed preliminary riprap-countermeasures at the critical location on the bridge (pier 3). Figure 5 is an aerial image of structure F-09-AF with the recommended scour countermeasure. Figure 6 is a cross-sectional view of the structure with the recommended scour countermeasure and appropriate geometry. As a part of analysis, cost estimates for alternate countermeasures were created for comparison.

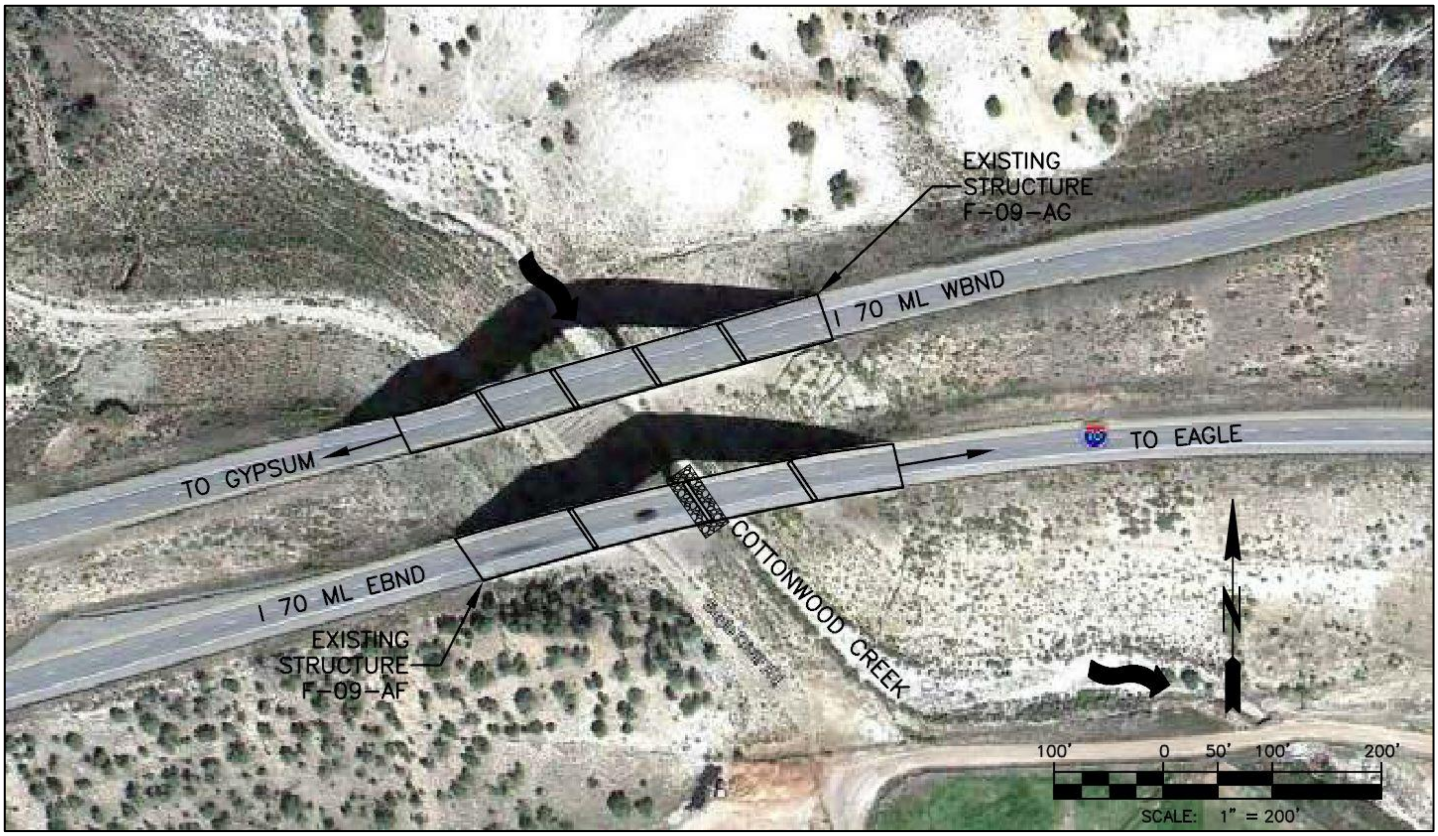


Figure 5. Plan view of Bridge F-09-AF with recommended hydraulic-scour countermeasure locations

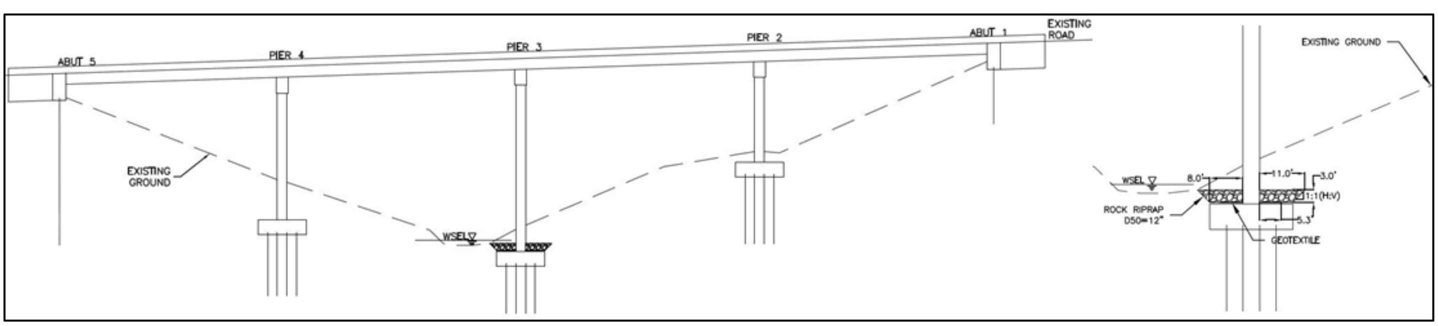


Figure 6. Cross-sectional view of Bridge F-09-AF with recommended hydraulic-scour countermeasures (left) and detail of pier protection (right)

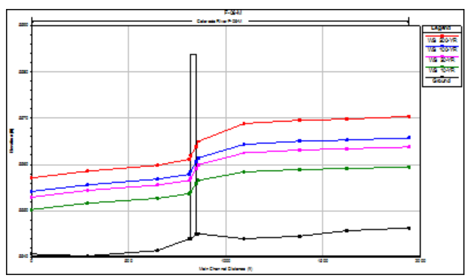
INTERSTATE 70 ACCESS BRIDGE F-06-M OVER COLORADO RIVER, COLORADO

Bridge F-06-M is located in Garfield County on the Interstate 70 access road where it crosses the Colorado River. Figure 1 shows Bridge F-06-M over the Colorado River.

Hydrau-Tech, Inc. began the POA study of Bridge F-06-M by collecting site and structure information including hydrologic characteristics, GIS information, and original bridge construction plans. A Log Pearson III gage analysis was completed using two Colorado-River gages, resulting in a 500-year flood discharge of 52931 cfs. After completing a survey of the reach upstream and downstream of the structure and analysis of sediment size, a HEC-RAS hydraulic model was developed. This model was used to estimate hydraulic conditions during the 500-year flow, including discharge distributions, velocity distributions, and water-surface profiles. Figure 2 shows the water-surface profile produced by the HEC-RAS hydraulic model. Figure 3 shows the reach-geometry plot produced by HEC-RAS.

Using the results from hydraulic modeling, theoretical scour estimates were calculated with FHWA's HEC-18 scour equations. AutoCAD drawings were produced with adjusted datum elevations and theoretical-scour lines in order to determine the stability of the structure under flood-scour conditions. Figure 4 shows a completed theoretical-scour plot created with AutoCAD, showing foundation elevations and potential scour.

Figure 7. Bridge F-06-M over the Colorado River



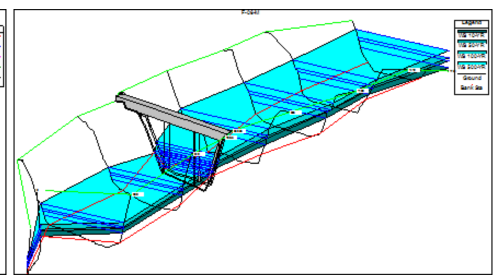


Figure 8 (Left). Water surface profile showing the 10-, 50-, 100- and 500-year flows
Figure 3 (Right). 3D plot of the reach around structure F-06-M

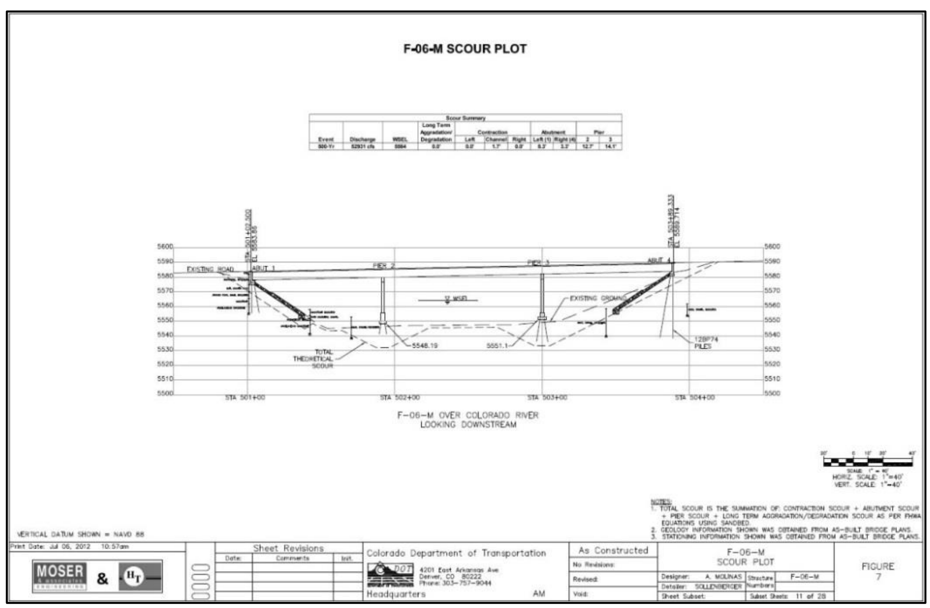


Figure 3. Scour plot generated in AutoCAD showing bridge geometry, foundation elevations, sediment bore-hole results and theoretical scour

Countermeasures were designed by Hydrau-Tech, Inc. based on theoretical scour and the current site conditions, such as foundation depths and existing structure protection. Riprap was chosen as the hydraulic scour countermeasure. Pier and abutment riprap sizing were determined using FHWA's equations. Based on theoretical velocities, riprap with a median grain-size diameter of 3.0 feet was included in the design of the abutment and pier protection. Using guidelines in HEC-23 for design of riprap protection, Hydrau-Tech, Inc. developed preliminary riprap-countermeasures at the critical locations on the bridge (right abutment and pier 2). Figure 5 is an aerial image of structure F-06-M with the recommended scour countermeasures. Figure 6 is a cross-sectional view of the structure with the recommended scour countermeasures and appropriate geometry. As a part of analysis, cost estimates for alternate countermeasures were created for comparison.

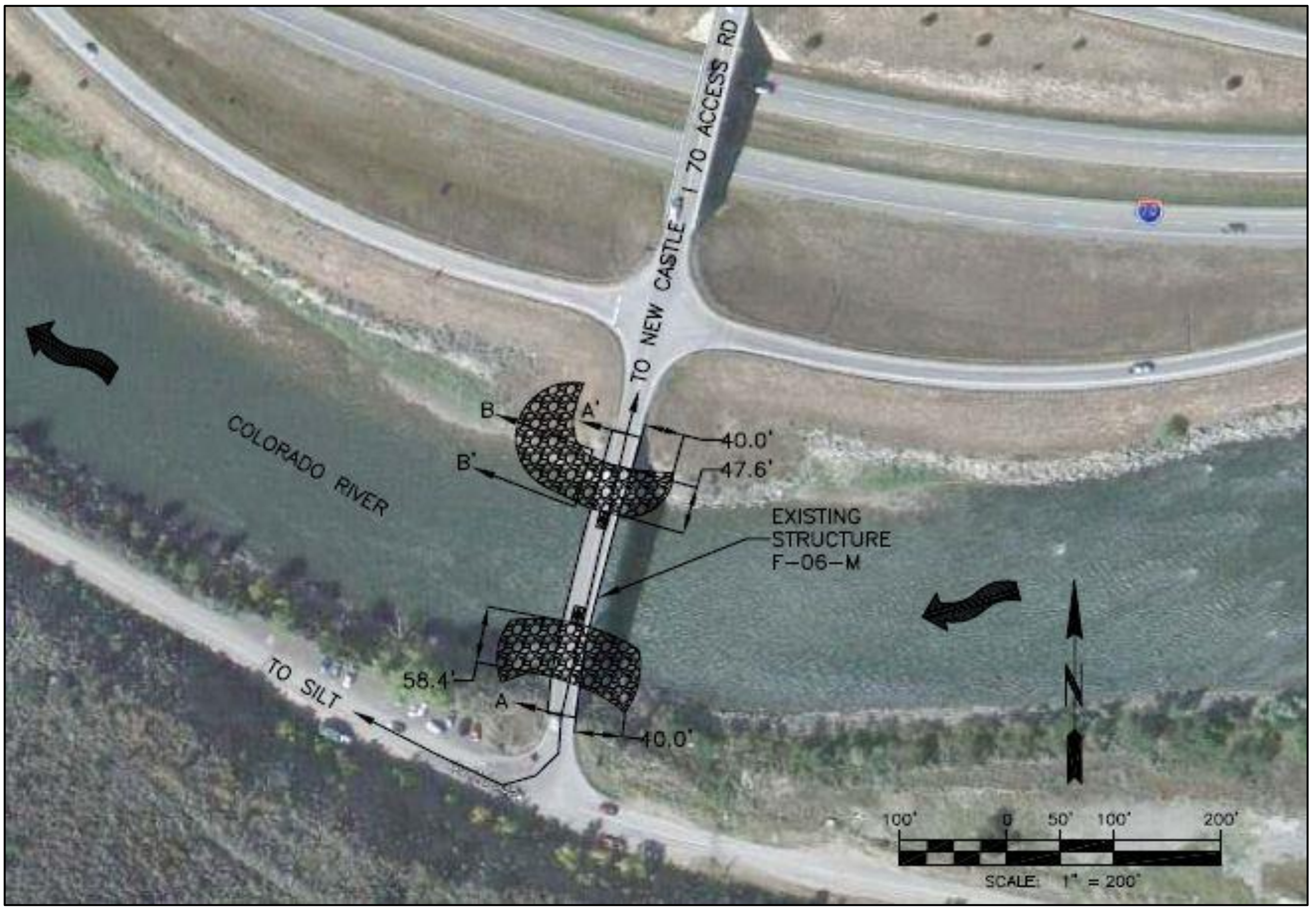


Figure 5. Plan view of Bridge F-06-M with recommended hydraulic-scour countermeasure locations

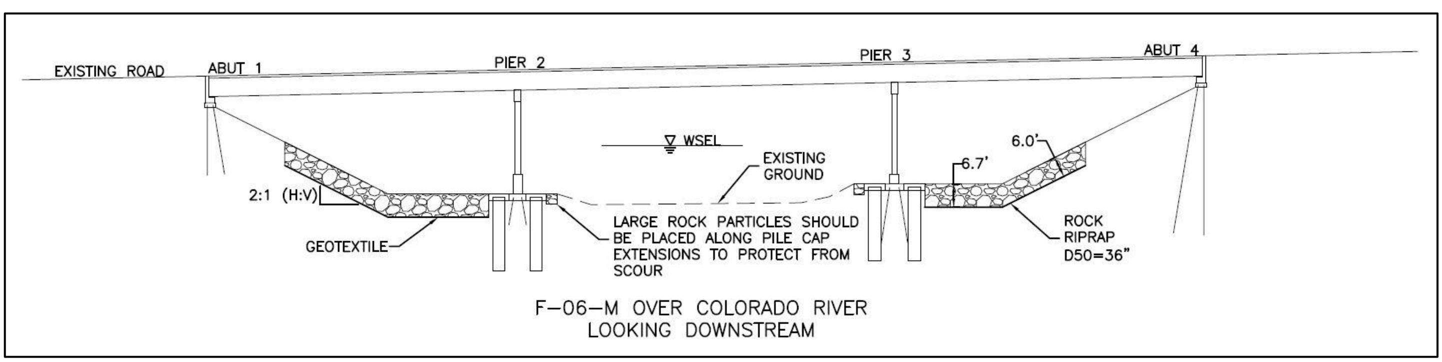


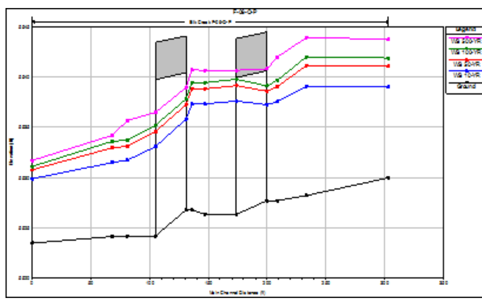
Figure 6. Cross-sectional view of Bridge F-06-M with recommended hydraulic-scour countermeasures

INTERSTATE 70 BRIDGE F-06-O AND F-06-P OVER ELK CREEK, COLORADO

Bridges F-06-O and F-06-P are located in Garfield County on the Interstate 70 mainline where it crosses Elk Creek. Figure 1 shows Bridges F-06-O and F-06-P over Elk Creek.

Figure 9. Bridges F-06-O and F-06-P over Elk Creek

Hydrau-Tech, Inc. began the POA study of Bridges F-06-O and F-06-P by collecting site and structure information including hydrologic characteristics, GIS information, and original bridge construction plans. Using this information, regional regression equations resulted in a 500-year flood discharge of 3410 cfs. After completing a survey of the reach upstream and downstream of the structure and analysis of sediment size, a HEC-RAS hydraulic model was developed. This model was used to estimate hydraulic conditions during the 500-year flow, including discharge distributions, velocity distributions, and water-surface profiles. Figure 2 shows the water-surface profile produced by the HEC-RAS hydraulic model. Figure 3 shows the reach-geometry plot produced by HEC-RAS.



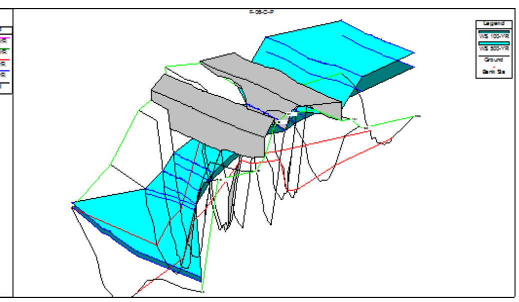


Figure 10 (Left). Water surface profile showing the 10-, 50-, 100- and 500-year flows
Figure 3 (Right). 3D plot of the reach around structures F-06-O and F-06-P

Using the results from hydraulic modeling, theoretical scour estimates were calculated with FHWA's HEC-18 scour equations. AutoCAD drawings were produced with adjusted datum elevations and theoretical-scour lines in order to determine the stability of the structure under flood-scour conditions. Figure 4 shows a completed theoretical-scour plot using AutoCAD, which shows foundation elevations and potential scour.

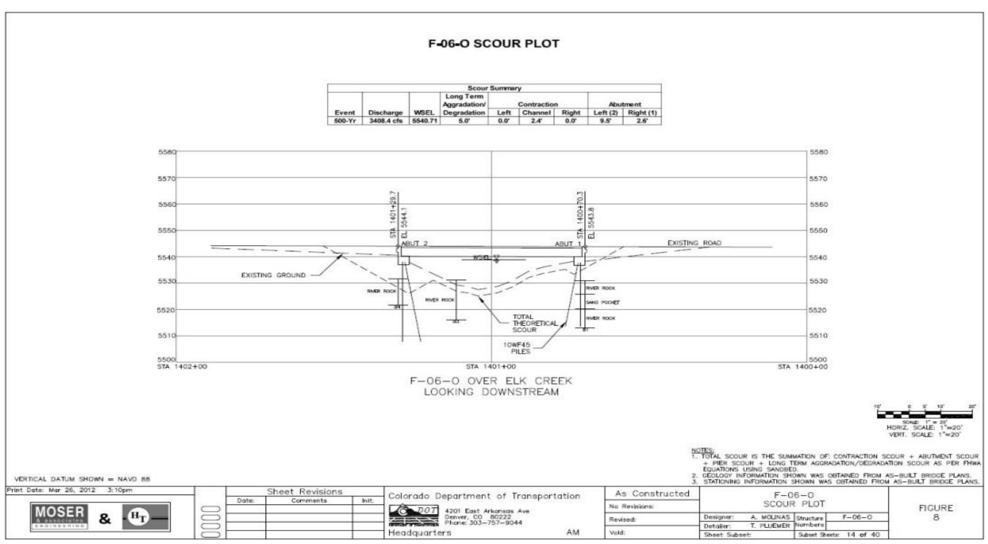


Figure 4. Scour plot generated in AutoCAD showing bridge geometry, foundation elevations, sediment bore-hole results and theoretical scour

Countermeasures were designed by Hydrau-Tech, Inc. based on theoretical scour and the current site conditions, such as foundation depths and existing structure protection. Riprap was chosen as the hydraulic scour countermeasure. Pier and abutment riprap sizing were determined using FHWA's equations. Based on the theoretical velocities, riprap with a median grain-size diameter of 3.0 feet was included in the design of the abutment and pier protection. Using guidelines in HEC-23 for design of riprap protection, Hydrau-Tech, Inc. developed preliminary riprap-countermeasures at the critical locations on the bridge (right abutment and pier 2). Figure 5 is an aerial image of structures F-06-O and F-06-P with the recommended scour countermeasures. Figure 6 is a cross-sectional view of the structure with the recommended scour countermeasures and appropriate geometry. As a part of analysis, cost estimates for alternate countermeasures were created for comparison.

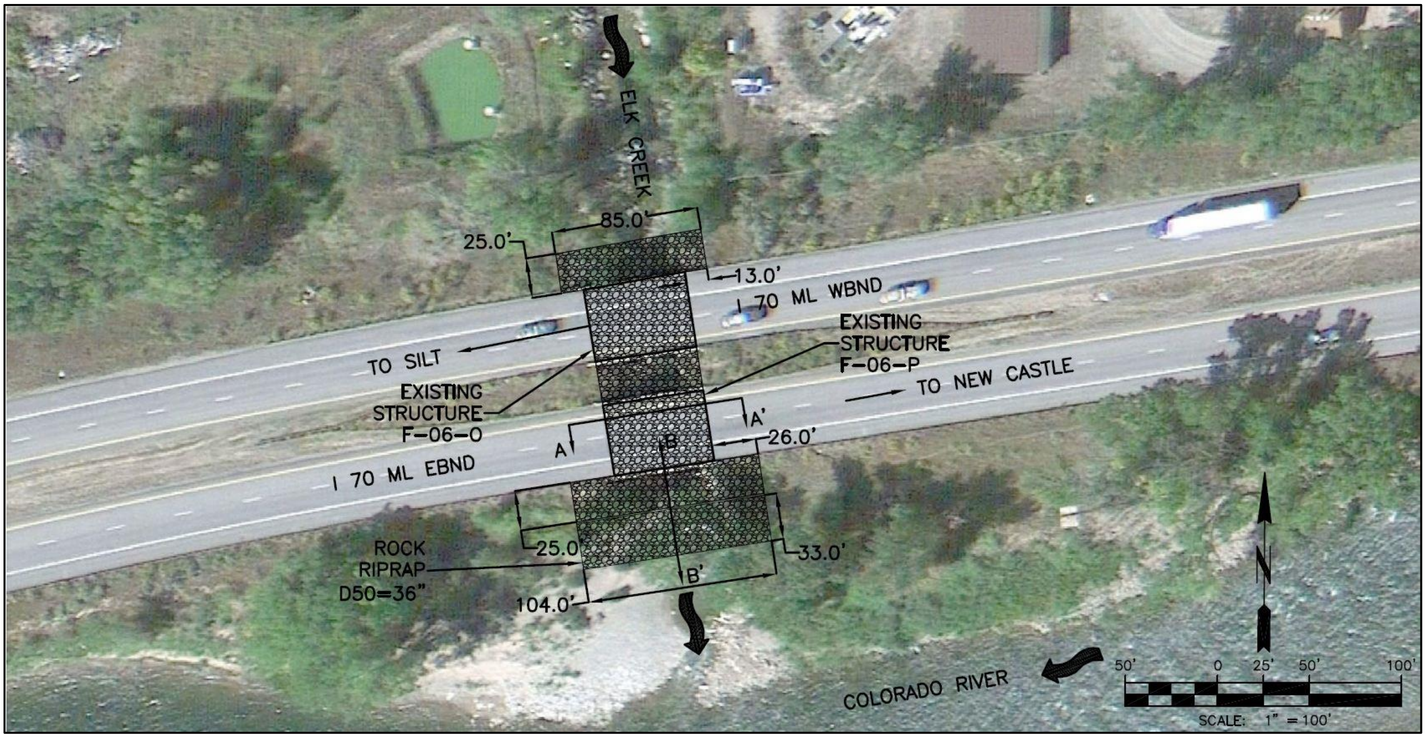


Figure 5. Plan view of Bridges F-06-O and F-06-P with recommended hydraulic-scour countermeasure locations

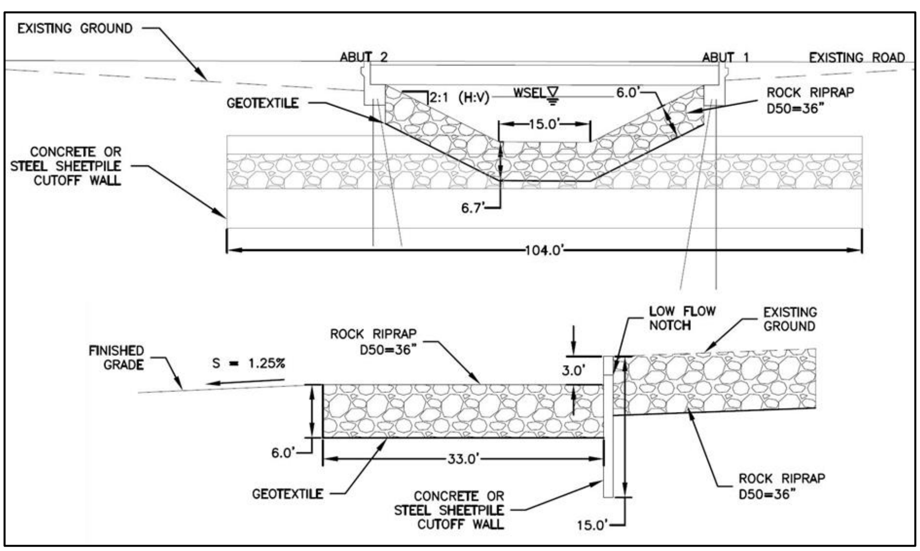


Figure 6. Cross-sectional view of recommended hydraulic scour countermeasures at Bridges F-06-O and F-06-P (above) and a profile view of the downstream drop structure (below)

SANMENXIA RESERVOIR SEDIMENT MODELING

Sanmenxia Reservoir is located in the lower part of the Middle Yellow River in China. It is a multi-purpose hydro-project, primarily used for flood control. Figure 1 shows the Sanmenxia Dam and its reservoir with one of its downstream outlets in operation. In this World Bank project, numerical modeling of a 150-km segment of the Yellow River upstream from the Sanmenxia Reservoir was accomplished using the GSTARS model, developed for the U.S. Bureau of Reclamation by Dr. A. Molinas of Hydrau-Tech, Inc.

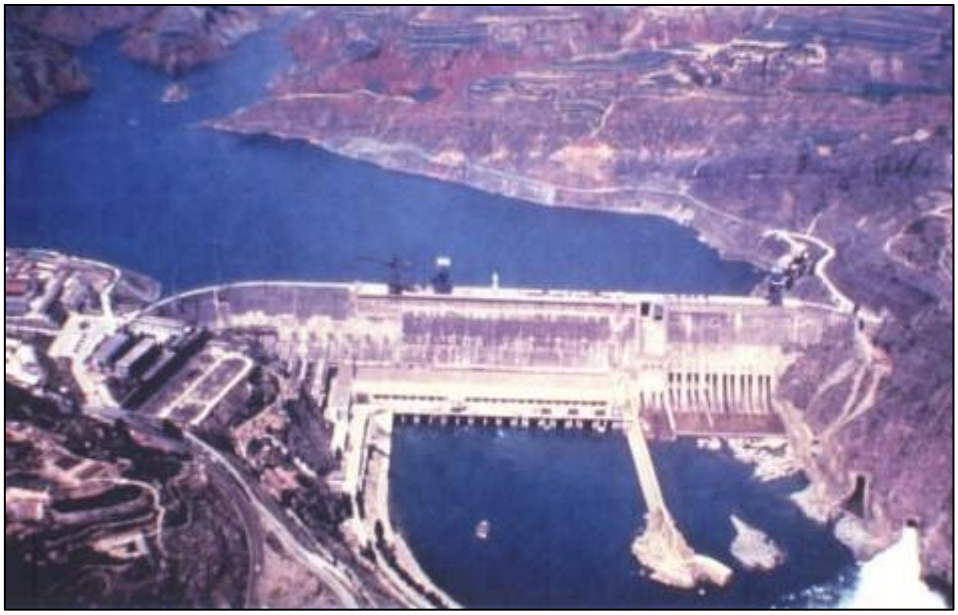


Figure 1. View of Sanmenxia Dam and its reservoir

The drainage area above the dam is 688,000 km^2. The Yellow River cuts through an extensive loess plateau where a 439,000-km^2 portion of it suffers from severe soil erosion (Figure 2). The channel flows carry up to 60% solids by weight, consisting mainly of fine sands and silts. Due to the large quantity of sediment carried by the Yellow River, Sanmenxia Reservoir was filled with sediment within a few years after its completion. Through sediment flushing during flooding season, the useful life of the reservoir was extended (Figure 3).

GSTARS is a water- and sediment-routing model for solving complex river-engineering problems. It is a semi-two-dimensional model that uses stream tubes to define lateral, as well as the longitudinal, variation of channel flows. Stream tubes are imaginary tubes bounded by streamlines. Since the discharge between streamlines remains constant in the direction of flow, the closer the streamlines and narrower the stream tubes, the faster is the velocity of flow.

Figure 2. Loess plateau that feeds large quantities of sediment to Yellow River.

Figure 3. Sediment- flushing operation through Sanmenxia dam releases up to 90% of solids.

Similarly, the wider apart the streamlines, and the larger the diameter of the stream tubes, the slower is the flow velocity. For ideal flows, total energy is constant along the stream tubes. For real fluids, it is possible to account for energy losses and compute velocity and depth variation along individual tubes. The basic equations used in the model include the energy equation, momentum equation, sediment-continuity equation, and various optional sediment-transport equations. For the Yellow River application, the GSTARS model was modified to accommodate site-specific characteristics of the river. Modifications included a new sediment-transport equation for fine sediments, consideration of non-equilibrium sediment transport, and computation of sediment transport-capacity by size fraction.

The GSTARS model for the Yellow River has been successfully used to simulate the typical reservoir operations given in Figures 4 and 5. Figure 4 shows the typical water- and sediment-inflow hydrographs for the reservoir. Figure 5 shows adopted reservoir operation rules for different time periods. Using this information, and measured channel topographies, roughness values, and sediment characteristics, numerical verification and validation runs were conducted. Figure 6 shows the close agreement with observed values. Using GSTARS, reservoir operation rules were refined to optimally pass oncoming sediments with minimal retention in the reservoir.

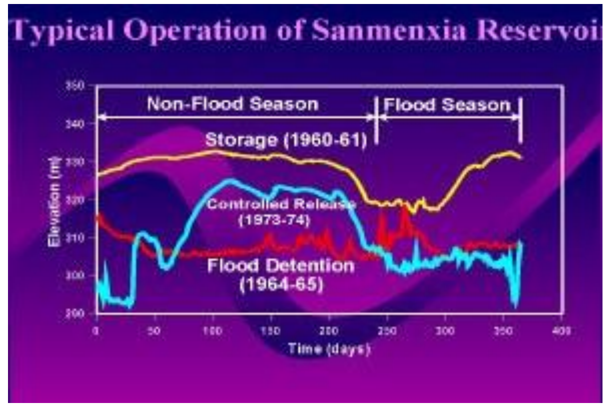


Figure 4. Water and sediment flow into Sanmenxia reservoir

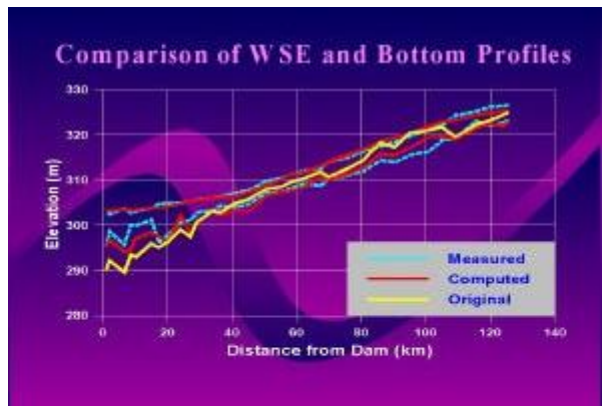


Figure 5. Typical operations. Sanmenxia reservoir stores water during non-flood season and releases it during flooding season

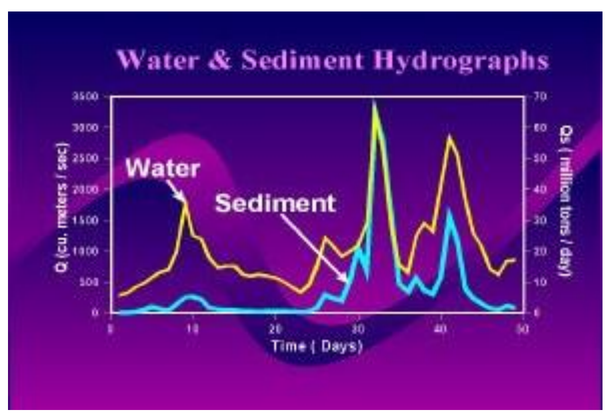


Figure 6. Comparison of simulated water-surface elevations and bottom profiles with observed values

NUMERICAL SIMULATION OF INTERSTATE 5 BRIDGE FAILURE NEAR COALINGA, CALIFORNIA

The Interstate 5 bridge that collapsed near Coalinga, California in 1998 carried up to 25,000 vehicles per day over Arroyo Pasajero Creek. Caltrans officials say they may never know why the bridge collapsed, but they have suggested two possible scenarios. In the first scenario, the water was so high and fast that it swept the bridge off its foundations. In the second, intense flow scoured the bed below the pilings and knocked the foundation out from under the bridge. The bridge was built in 1967 and was 120-feet long and 40-feet wide. Pilings were 12- feet deep. Figures 1 through 3 show the failed bridge.

Figure 1. View of the failed bridge looking upstream.

Figure 2. View of the failed bridge from the channel facing downstream. Note the failed left abutment.

Figure 3. View of the failed bridge from the channel facing downstream. Note the failed left abutment.

As a part of **BRI-STARS** (BRIdge Stream Tube Alluvial River Simulation) Model Development and Enhancement Project, the Interstate 5 bridge and Arroyo Pasajero Creek segments immediately upstream and downstream from the bridge were simulated. Using topographic, hydrologic and sediment data provided by the U.S. Geological Survey, the magnitude of scour due to the scouring action of flows was computed to determine the cause of failure. Simulations showed that up to 11-feet of scour occurred at the bridge opening, and that the bridge failure was due to intense scour of foundation.

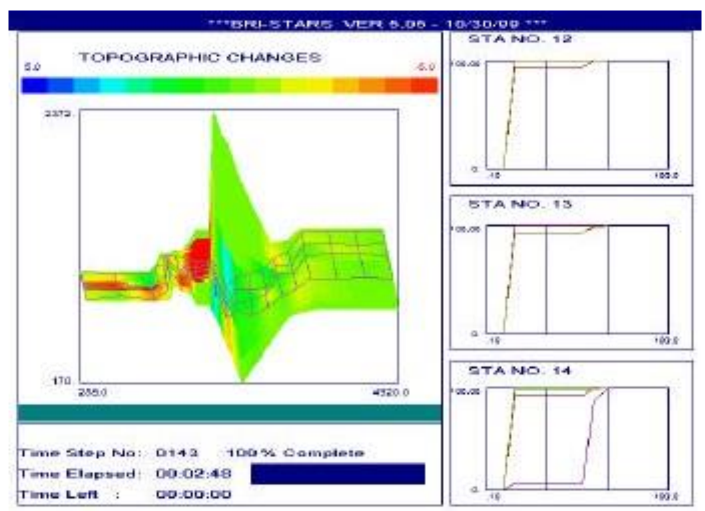


Figure 4. Topographic Changes window of BRI-STARS model showing the red-colored bridge scour zone and the blue-colored deposition immediately upstream from bridge for comparison with Figure 1

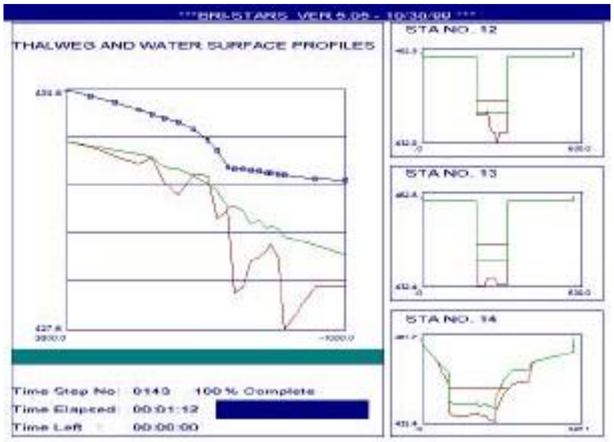


Figure 5. Thalweg and Water Surface Profiles window showing the initial (green) and final (red) ground profiles of study reach.

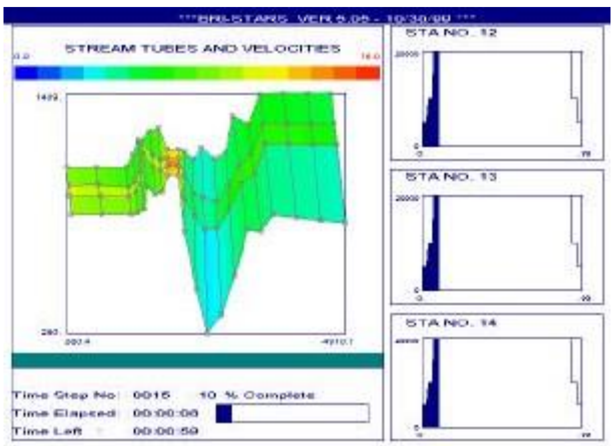


Figure 6. Stream Tubes and Velocities window showing the plan view of the study reach and color-coded velocity distribution

BRI-STARS was developed to solve complex alluvial river-sedimentation problems by Dr. Albert Molinas, President of Hydrau-Tech, Inc., for the Federal Highway Administration . This semi-two-dimensional model divides a stream channel into a series of stream tubes. Stream tubes are imaginary tubes bounded by streamlines. They carry a constant discharge along their length. Water and sediment is routed along each stream tube by satisfying the governing flow and sediment-transport equations. BRI-STARS utilizes both the conservation of momentum and energy equations to compute water-surface profiles through sub-critical, supercritical, and the combination of both flow types involving hydraulic jumps. State-of-the art sediment-transport equations, bridge-scour relationships, and sediment-sorting algorithms are used to compute scour and deposition processes in river systems.

BRI-STARS is a visually-interactive model. Users can follow the progression of computations through simulation times. Lateral scouring and deposition processes, as well as longitudinal changes can be viewed through animation of cross-section changes or thalweg profiles. Changes in channel topographies, and velocity variations along the channel and across the tubes are color coded and displayed in separate windows.

Figures 4 through 6 show the windows displaying the various aspects of computations during the simulation run for the Interstate 5 bridge-scour study. Figure 4 shows computed scour patterns at the bridge site and in the area. Figure 5 displays thalweg profiles at the beginning and end of a flooding event. It also shows cross-sectional changes through the bridge and immediately downstream. Figure 6 displays a computed two-dimensional velocity field along the study reach through the contracted bridge opening.

The computed scour compared very closely with the measured scour from a detailed field analysis conducted at a later date by the U.S. Geological Survey. The numerical simulation clearly demonstrated that the bridge failure was due to excessive scouring of the foundation.

DESIGN OF CROSS CULVERTS FOR COLORADO STATE HIGHWAY 82 PROJECT IN SNOWMASS CANYON

In this Colorado Department of Transportation project, large debris-flow culverts were designed crossing a new four-lane section of State Highway 82 near Aspen, Colorado. Along the project site, the highway passes through Snowmass Canyon along a series of small debris-producing watersheds shown in Figures 1 and 2.

Culvert designs were based on computer modeling results from Federal Highway Administration's BRI-STARS model. As a part of the project, a BRI-STARS model developed earlier by Dr. A. Molinas of Hydrau-Tech, Inc. was modified to accommodate debris flows by including various theoretical formulations. Traditional clear-water modeling methods result in considerably undersized culverts for debris flows. Culvert sizes that can pass the design discharges were accurately computed using BRI-STARS modeling of viscous mudflows.

Figure 1. View of State Highway 82 in Snowmass Canyon

Figure 2. Debris flow fans along Colorado State Highway 82

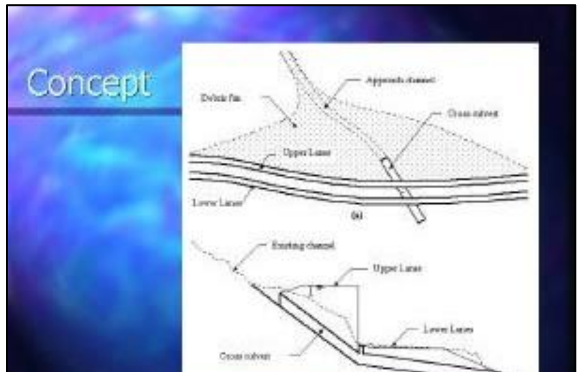


Figure 3. Conceptual design of highway cross culverts for conveying upstream debris flows.

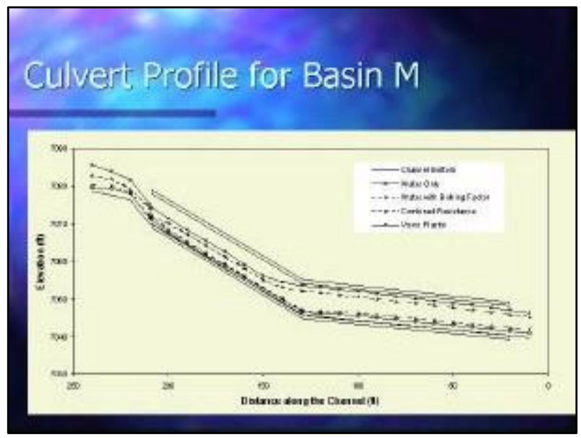


Figure 4. Computed debris flow profiles along with profiles computed using only water, and bulked discharges

In order to widen the existing two-lane highway to four lanes along the narrow canyon, a split configuration was utilized. Space for the additional two lanes going from Glenwood Springs to Aspen was created by encroaching on the canyon wall. This included building a retaining wall and elevating the upper lanes as much as 30 feet. At 8 locations along the path, basins producing debris fans border the highway. Potential debris flowing from these basins is passed beneath the highway without interrupting traffic, as shown in Figure 3. Figure 4 shows the computed debris-flow profiles for one of the basins.

These flow profiles were generated using the enhanced BRI-STARS model by incorporating a viscous-plastic fluid-flow component.

Figures 5 and 6 show the elevated section of highway cutting through a debris fan at the base of Basin H.

Figure 7 shows a culvert design for the watershed identified as Basin I. It does not require a break in the invert slope due to the location of the crossing. The cast-in-place culvert outlet and typical sections, as well as the construction of elevated sections of the highway, are shown in Figures 8 and 9.

Figure 5. Elevated segment of State Highway 82 crosses a debris fan at the base of Basin H

Figure 6. State Highway 82 crossing debris-basin H

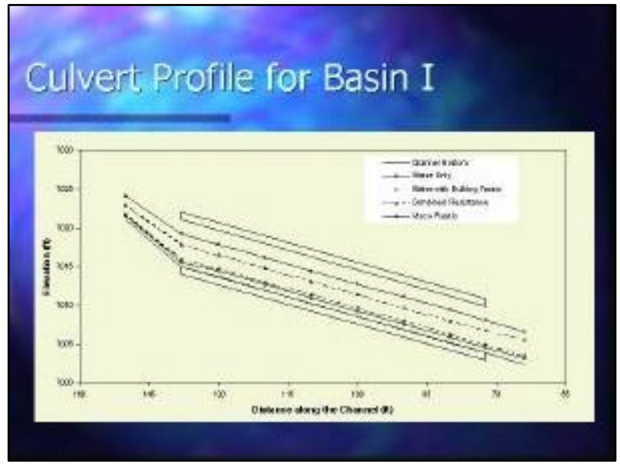


Figure 7. Computed debris flow profiles for Basin I

Figure 8. Construction of upper lanes at Basin I

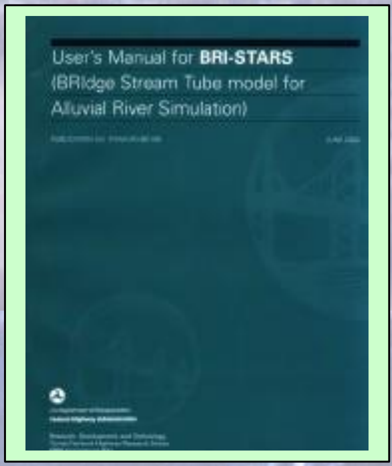
Figure 9. Culvert outlet and pre-fabricated culvert sections

HYDRAU-TECH MANUALS AND CONFERENCE PROCEEDINGS

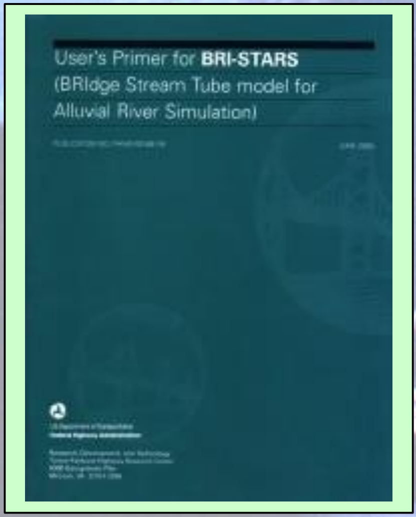
Hydrau-Tech, Inc. personnel have published numerous scientific articles appearing in journals of professional societies and conference proceedings. In addition, Hydrau-Tech personnel have authored and co-authored computer user's manuals and conference proceedings, and participated in preparation of textbooks and handbooks.

GSTARS User's Manual for U.S. Bureau of Reclamation by Molinas and Yang

Proceedings of the International Conference on Reservoir Sedimentation for UNESCO & IAHR (Vols. 1, 2, and 3) by Albertson, Molinas and Hutchkiss



BRI-STARS User's Manual for Federal Highway Administration By A. Molinas



BRI-STARS User's Primer for Federal Highway Administration By A. Molinas

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