Lower Crabby Creek Restoration

Learning the Art and the Science

INTRODUCTION

This slide presentation is the first part of an on-going account of the restoration of Crabby Creek, a small cold water feeder stream to Little Valley Creek, just north of Paoli, Pennsylvania, in suburban Philadelphia. The stream is part of the Valley Creek Watershed that includes Valley Forge National Historical Park. Crabby, a well wooded brown trout nursery stream, suffers the ravages of storm water run-off from the impervious surfaces of the development in its headwaters. By 2008 the erosion of about 3500 cubic feet of streambed had undercut a sanitary sewer line that carries a million gallons of waste per day, creating a potential environmental disaster.

Restoration sponsor

Valley Creek
Restoration Partnership

VALLEY CREEK
RESTORATION PARTNERSHIP

Who is the Valley Creek Restoration Partnership?

Core Partners:

- Green Valleys Association
- League of Women Voters
- Open Land Conservancy of Chester County
- Valley Forge Chapter of Trout Unlimited
- West Chester Fish Game & Wildlife Association

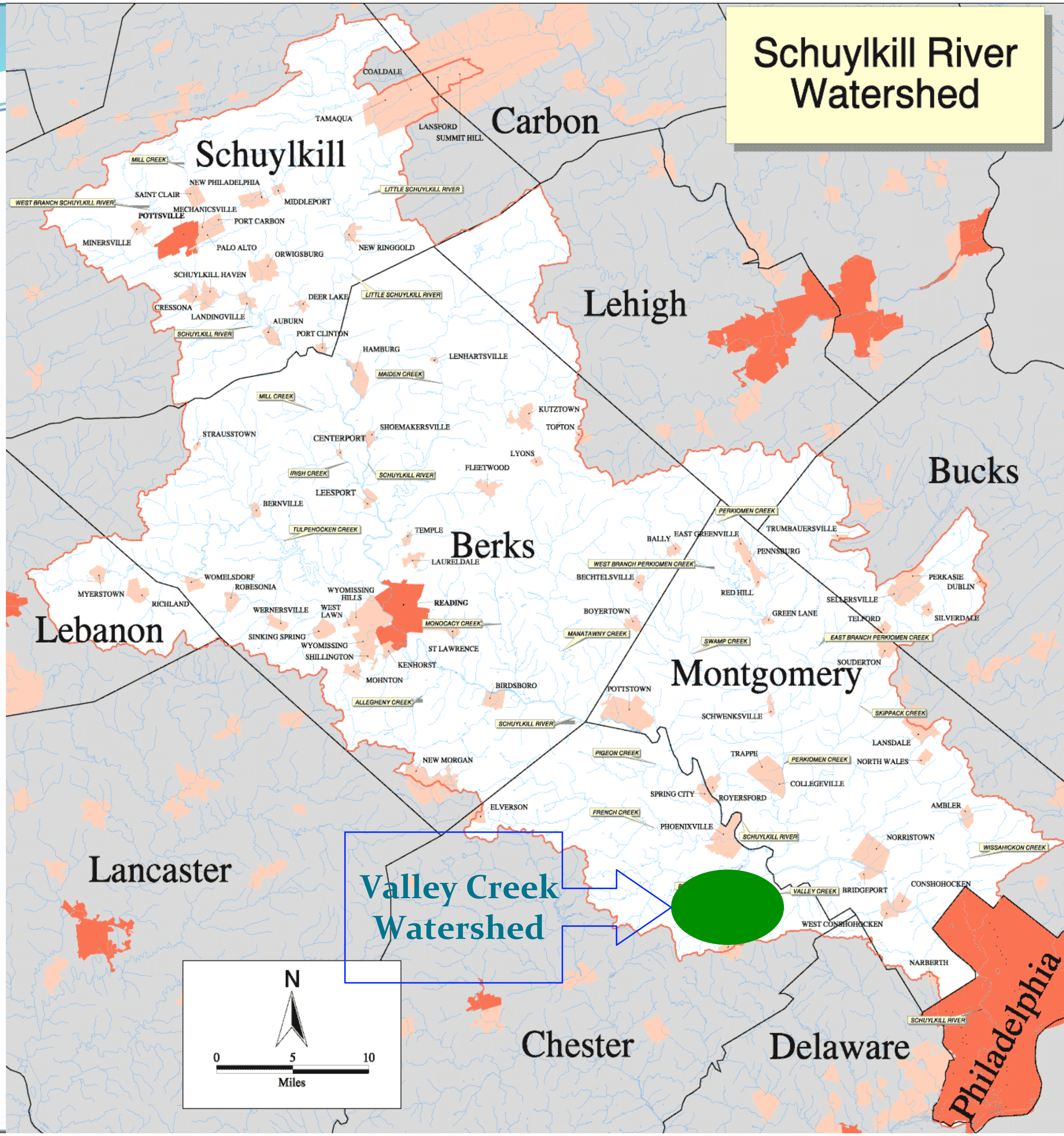
acting in concert with

Associates and Advisors:

•East Whiteland Township
•Tredyffrin Township
•Chester County Conservation District
•Chester County Water Resources Authority
•PA Department of Environmental Protection
•PA Fish & Boat Commission
•Valley Forge National Historical Park

•U.S. Geological Survey
•Cabrini College
•Drexel University
•Temple University
•University of Maryland
•Villanova University

The Valley Creek watershed is located in the SW corner of the Schuykill River Watershed, just NW of Philadelphia

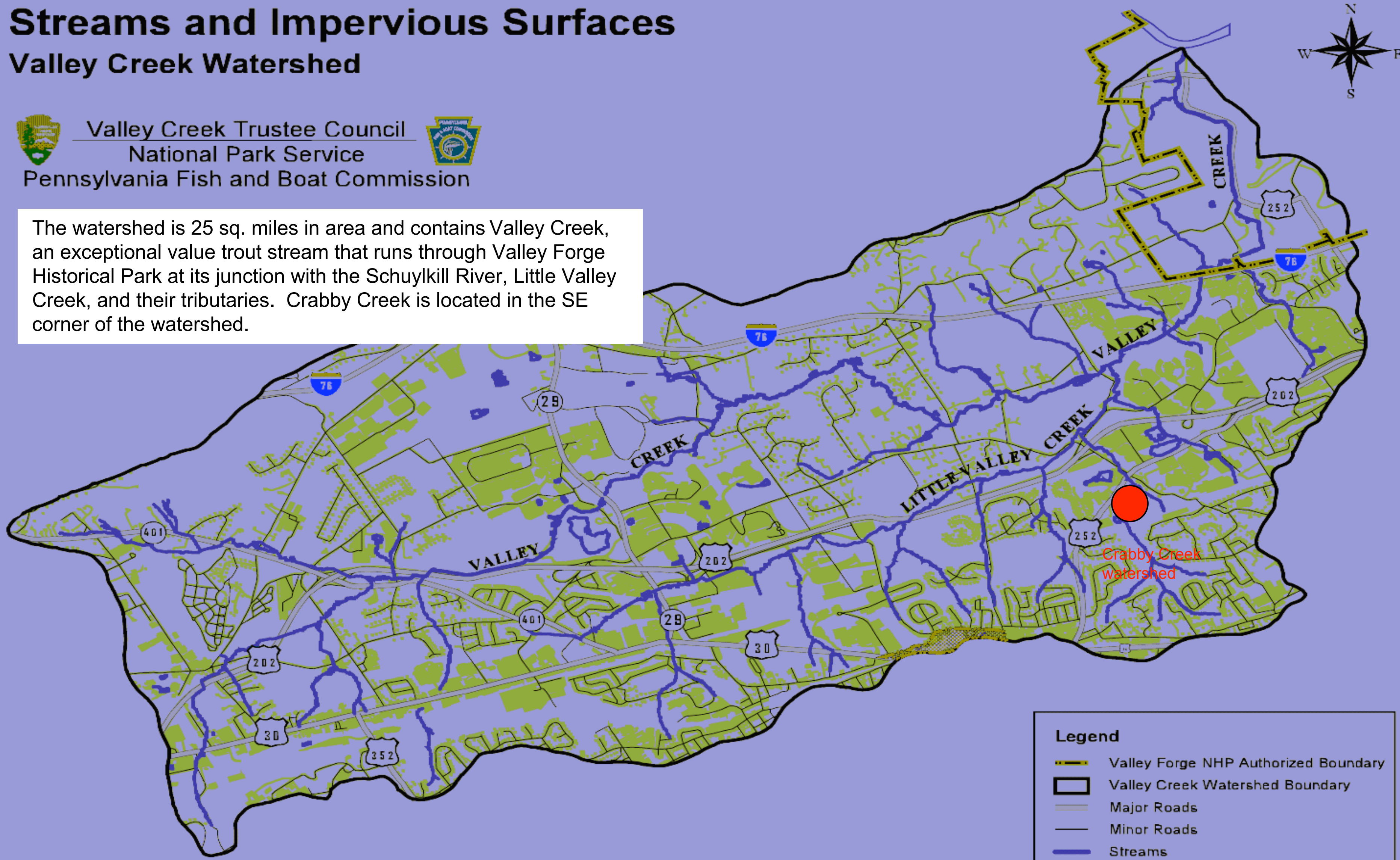


Streams and Impervious Surfaces

Valley Creek Watershed

Valley Creek Trustee Council
National Park Service
Pennsylvania Fish and Boat Commission

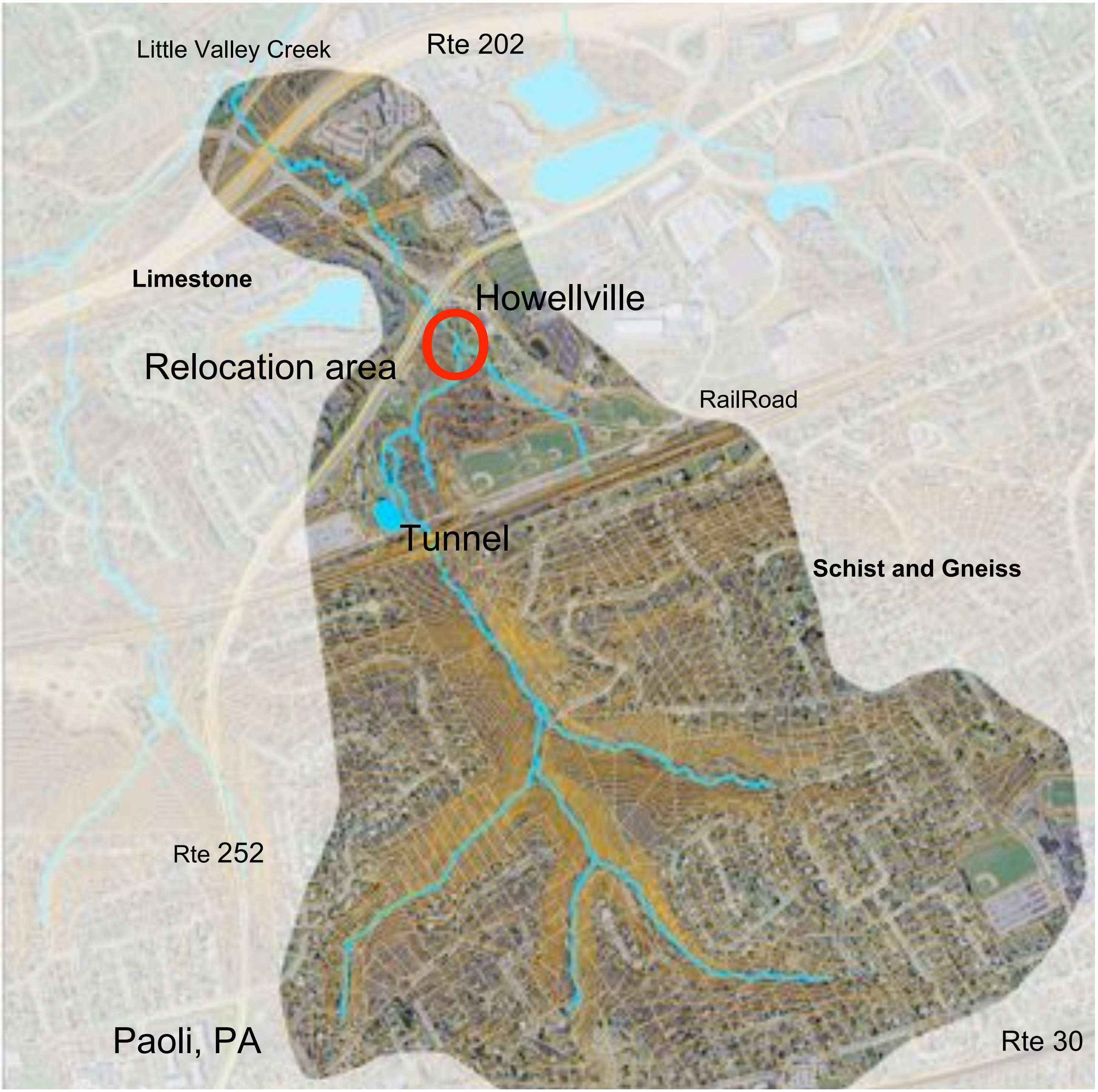
The watershed is 25 sq. miles in area and contains Valley Creek, an exceptional value trout stream that runs through Valley Forge Historical Park at its junction with the Schuylkill River, Little Valley Creek, and their tributaries. Crabby Creek is located in the SE corner of the watershed.



Data Sources: Valley Creek Watershed data was compiled from various sources and created by Cahill Associates, 2000; Valley Forge NHP boundary was created by NC State University, and updated by VAFO staff, 2002;

CRABBY CREEK WATERSHED

Crabby Creek flows north through a 1.25 sq. mile watershed just North of Paoli, Pa. The upper watershed is located in heavily wooded steeply sloped terrain underlain by schist and gneiss bedrock. The stream has cold water springs throughout its length. The lower stream, just North of the tunnel under the railroad, is underlain by limestone bedrock The area of the relocated part of the restoration is within the red circle on the map.

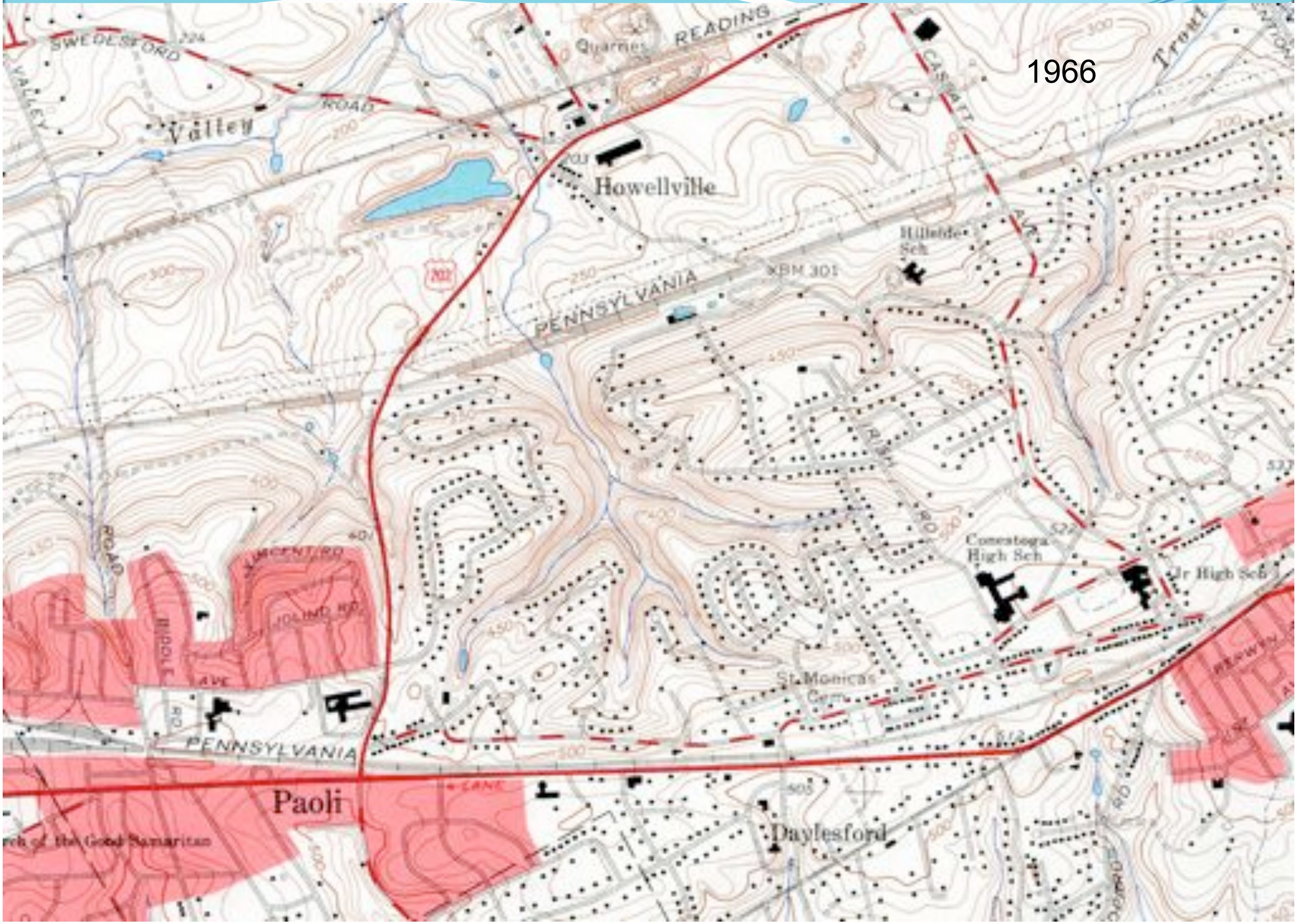


Crabby Creek Attributes

Crabby Creek is a quality cold water stream that supports trout and beneficial cold water insects and has springs throughout its length. It was the historic drinking water source for the village of Howellville. The upper watershed down to Howellville is surrounded by a significant forested buffer and is well shaded.

The watershed was mostly developed by the 1960-1980 timeframe, as indicated on the map on the next slide. Because of this build out increased run-off from future infrastructure will be limited. In fact, good local storm water ordinances in Tredyffrin Township put in effect after 2004 require infiltration of any new impermeable surfaces over 500 sq. feet.

1966



SWEDESFORD
ROAD
READING
Quarries
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Conestoga High Sch
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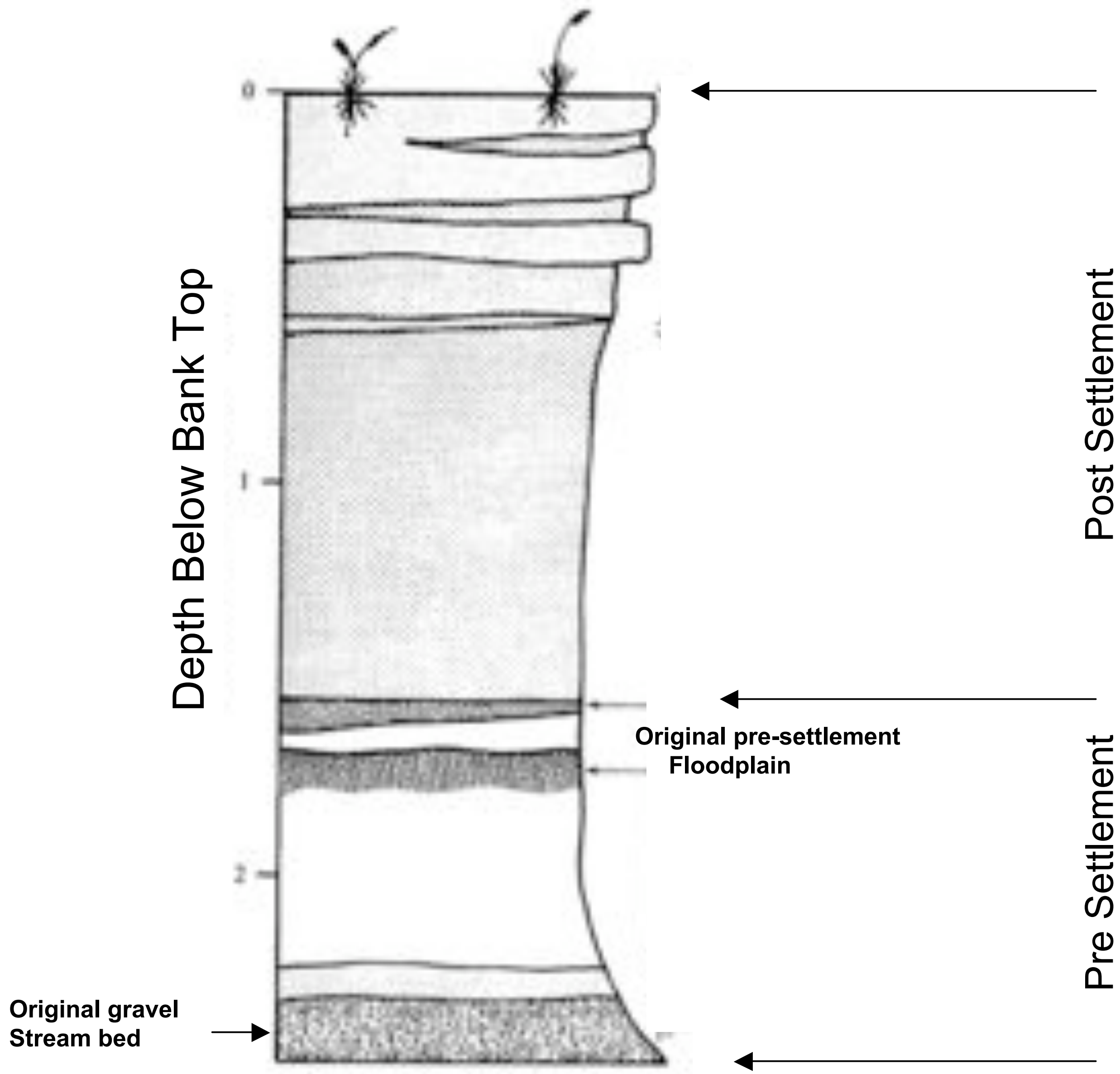
Crabby Creek Problems

There are significant problems in the Crabby Creek Watershed that need to be recognized before embarking on any restoration of the stream. First, a thick layer of easily eroded silt covers the original valley bottom below the railroad tunnel. This started accumulating in post colonial times. There are impervious surfaces covering 30% of the land from development in the watershed, the drainage from which is piped directly to the stream and is responsible for heavy storm run-off. Steep slopes in the upper watershed and straightened steam channels dues to parallel sanitary sewer lines speed the run-off, creating an unstable, flashy stream during rainstorms and resulting in considerable erosion of the banks and underlying silt. This sediment load degrades the lower stream and ends up in Little Valley and Valley Creek, degrading their habitats.

This is a view of the Crabby looking downstream in the upper watershed just below the junction of the branches. Until the late 1990's Crabby held a wild population of naturally reproducing brook trout that we believe was washed out by a hurricane. The stream still has a wild population of brown trout, and trout move up from Little Valley Creek into Crabby to spawn in the Fall.

Piedmont Valley Sediment Layers



The lower part of the Crabby watershed below the railroad tunnel is underlain by a thick sediment layer, similar to that described in other Piedmont valleys. The layer was the result of post settlement deforestation due to logging and agriculture on the uplands and in Crabby, later quarrying operations and installation of a sewer line in the 1970's along the stream. Crabby sediment profiles are illustrated on the following slide.

R. Jacobson and D. Coleman, STRATIGRAPHY AND RECENT EVOUTION OF MARYLAND PIEDMONT FLOOD PLAINS, American Journal of Science, Vol. 286, October, 1986, pp 617-637

Sediment Profiles in lower Crabby Creek

Impervious surfaces in the Crabby Creek Watershed

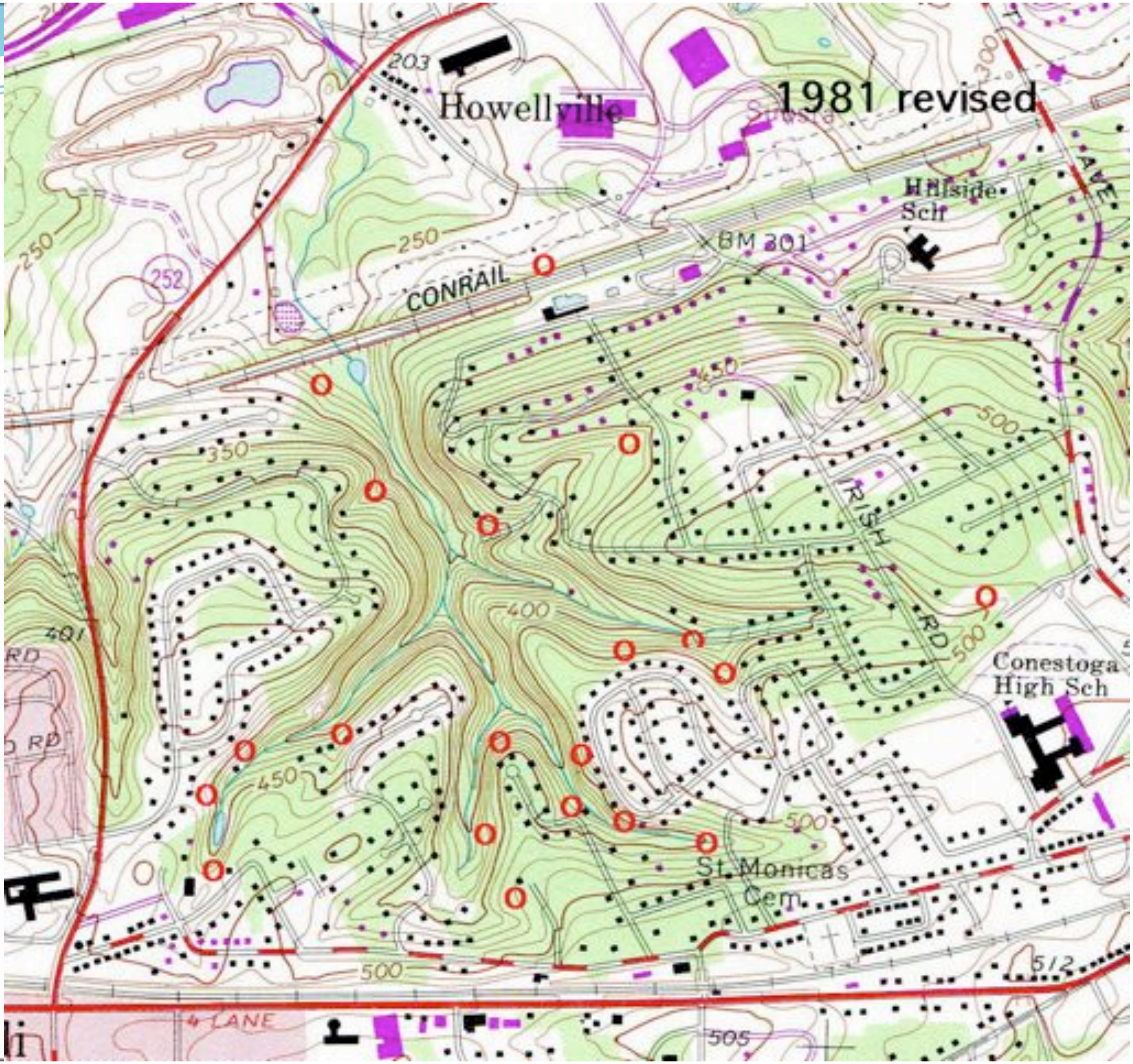
• Roads	19.0%
• Resident. Rooftops*	5.2%
• Driveways*	1.8%
• Commercial/Business*	4.4%
TOTAL IMPERVIOUS:	30.4%

* Crabby Creek Watershed Study, LandStudies, June 2005

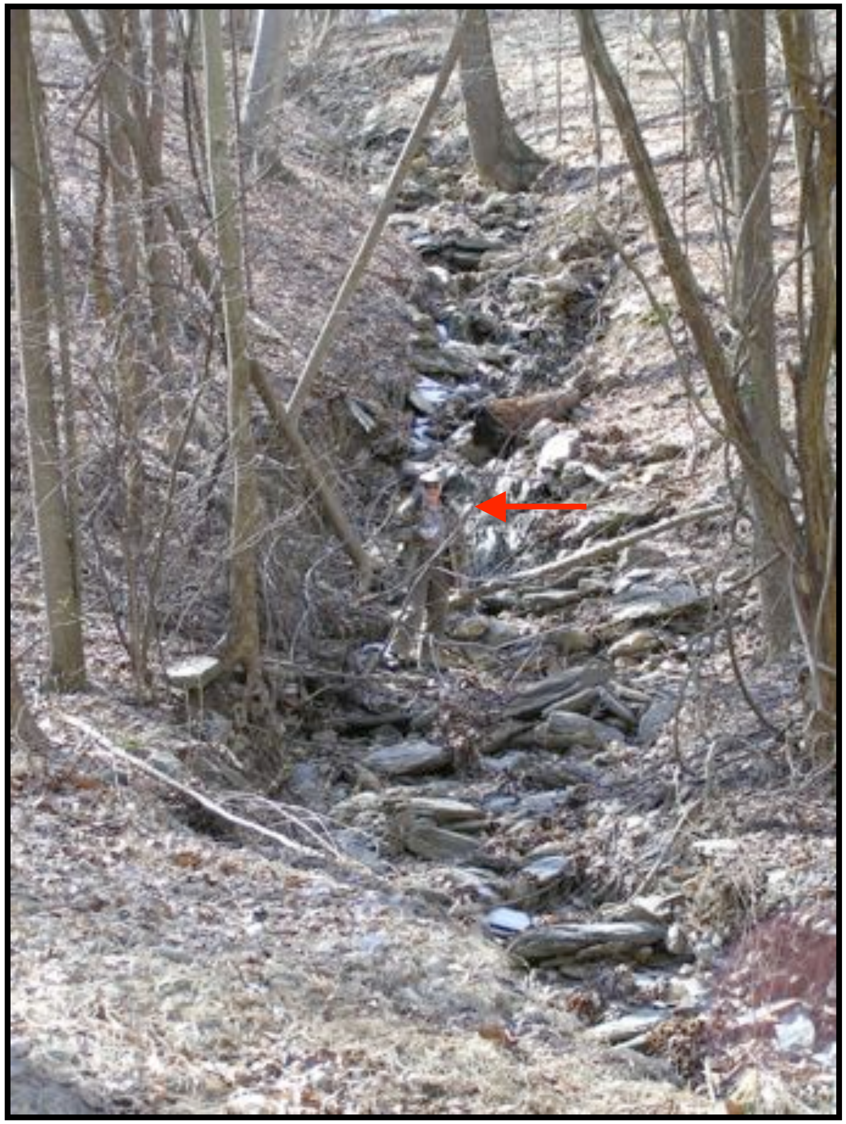
20 stormwater outfalls

Marked by 0

All of the impervious surfaces- roads, driveways, roofs, and lawns are piped directly to the stream at stormwater outfalls below street inlets



Erosion below outfall



For scale,
note the person
standing in the
eroded swale.

Sanitary Sewers Along All Branches Crabby Creek

Installed in mid 1970's, these sanitary sewer lines straightened the stream, cut off its access to flood plain, and created an abundant supply of easily eroded sediment from the backfill along the stream banks, as shown on the next slide.

Sewer lines Shown in Red

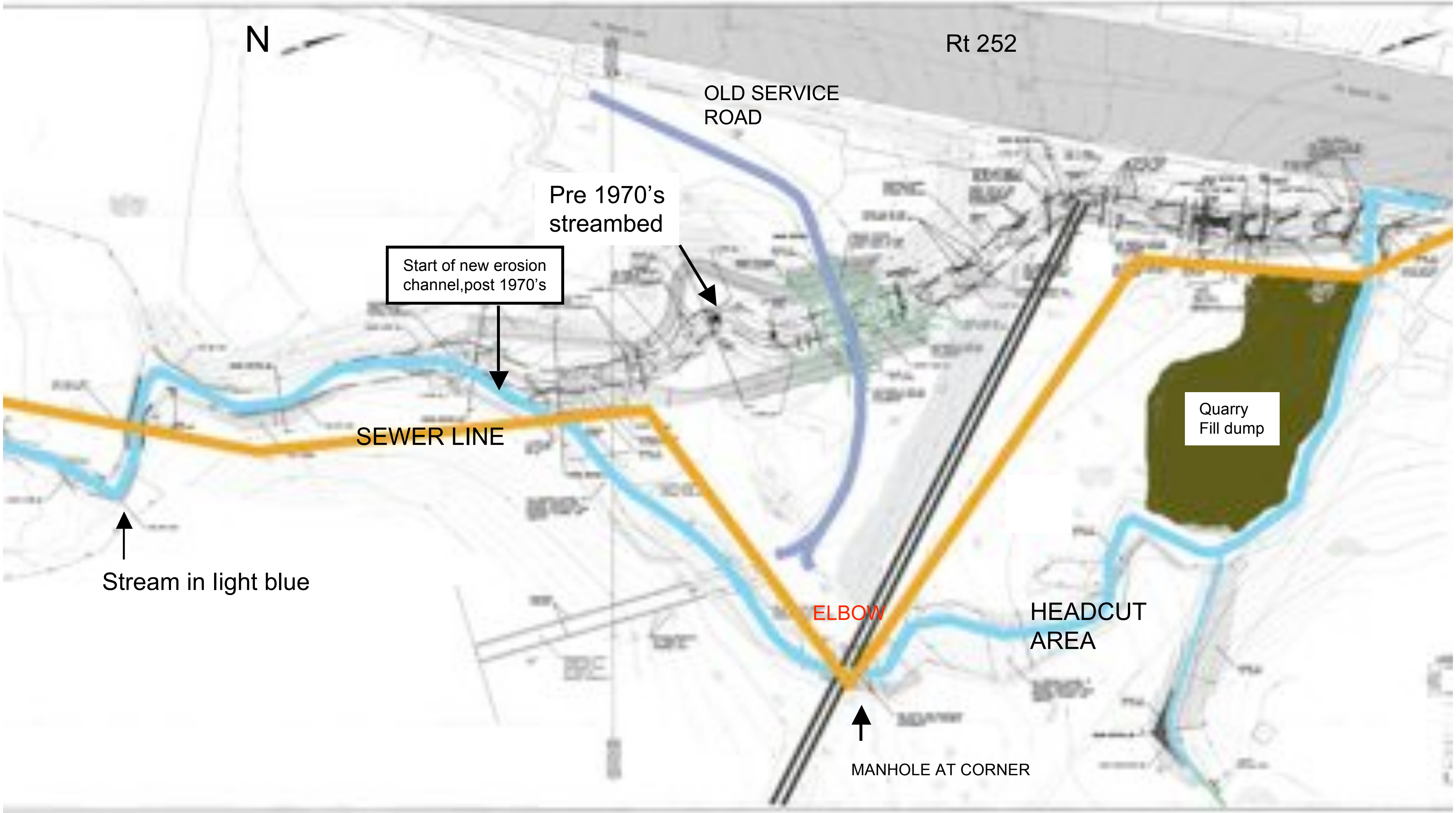
EROSION ALONG SEWERLINES

Erosion of sewer line fill
in stretch upstream
from tunnel under railroad →

Erosion even in
occurs along the sewers
the upper headwaters

DOWNSTREAM COURSE OF CRABBY BELOW RAILROAD TUNNEL AT RESTORATION SITE IN 2008

This is a map of the restoration area (below the RR tunnel) as it was in 2008. This area is underlain with post colonial sediment, as shown on a previous slide, as well as old waste from a nearby quarry. The sanitary sewer line was built in the mid-1970's; the elbow in the line was to go around a bedrock outcropping. The stream prior to the 1970's flowed in a bed west of the line. A service road shown in darker blue was built (with an undersized culvert) to allow the stream to pass under it. At some later time, the culvert got blocked and the stream eroded a new path along the sewer. A head cut formed in the streambed below the elbow sometime prior to 2004, and started upstream toward the sewer manhole at the bend of the elbow- as will be illustrated over the next several slides.



Calculated Discharge Rates Vs. Storm Events*

Land Studies Corporation, in a 2005 study of the Crabby watershed, calculated the run-off created by rainstorms of increasing size. Note that a rain event of about 2.6 inches within 24 hr. period, a storm with an approximate probability of once a year, would create a channel eroding flow of about 160 cubic feet per second, as compared to a summer base flow if 1 cubic foot per second. Two views of a 160 cfs flow in the post 1970 stretch cut alongside and below the sewer line are shown on the next slide.

RainStorm Event	TR-20 Calculated Discharge in cfs at RR Tunnel
1 yr.- 2.6"	160 cubic feet per second
2yr.- 3.2"	286 cfs
5 yr.- 4.2"	535 cfs

measured summer base flow = 1 cfs

* Crabby Creek Watershed Study, LandStudies, June 2005

Channel in flood

2005 2"+ storm

The powerful flows caused incision of the silt below the roots of the trees along the stream bank in the eroded reach below the elbow in the sewer line, causing them to be ineffective at holding the banks because of undercutting below the roots. This is a common problem in streams located in areas with legacy silt.

2008 2"+ storm

Eroded stretch along upper part of elbow in sewer line

These kinds of flows seriously and quickly eroded the silt under and in the banks of the stream, here forming a **headcut** -a nearly vertical drop in streambed elevation formed by the excess energy of the high flows. Headcuts migrate upstream as they widen and deepen the channel. Note the manhole in the sanitary sewer line elbow in the upper righthand corner, about 100 feet upstream.

MAJOR HEADCU

FEB. 9, 2004

UPSTREAM MOVEMENT OF HEADCUT

Within a year, this head cut had moved quickly upstream and started to undercut the 1 million gallon per day sanitary sewer line.

GOALS

Our challenge was to stabilize a steep-sloped stream of high energy, carrying a lot of runoff and sediment from a highly impervious watershed, through a bottom area of easily eroded soils. We needed a restoration that would stabilize the stream at high flows, limiting the erosion within its bed, but able to carry upstream sediment through from above to prevent blockages.

Such stabilization should also enhance the aquatic habitat, making it more favorable for trout to live and reproduce, and also be more favorable for aquatic insects. We intended to monitor the physical and biological outcomes of the restoration, expecting a generally positive result that would serve as a model for similar sub-water sheds in the Valley Creek watershed.

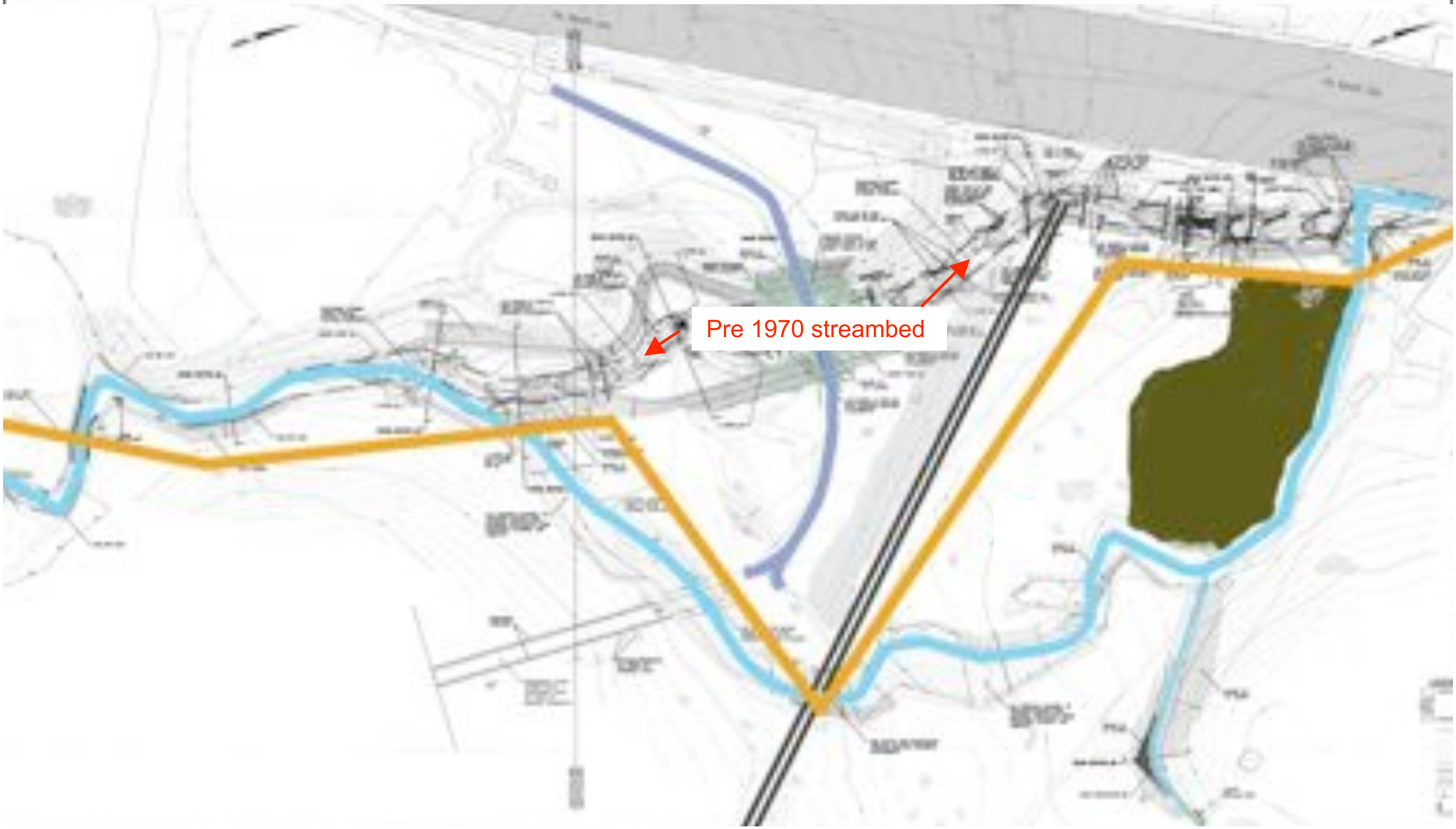
The restoration partnership also knew that it was imperative to initiate projects in the residential development in the headwaters to start getting the excess run-off infiltrated back into the ground, but the immediate restoration of the stream was imperative to remove the threat that it was posing to the sanitary sewer line.

The William Penn Foundation Implementation Grant

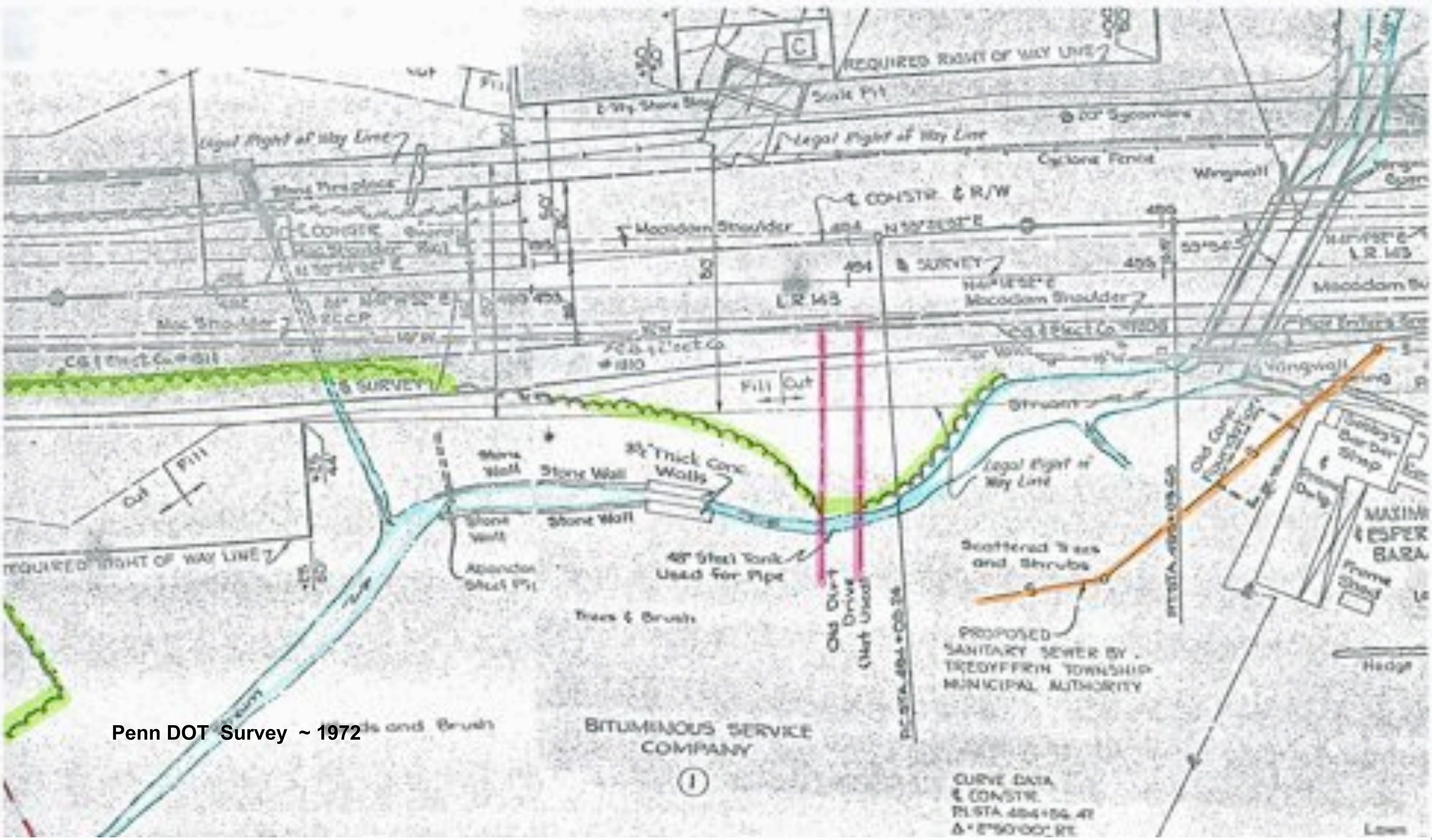
The Valley Creek Restoration Partnership applied for and was awarded a grant from the William Penn Foundation for three infiltration trenches in the upper Crabby watershed at stormwater inlets and the restoration of 1300 feet of the stream just upstream from the RT 252 culvert, in the region of the headcut. The grant money was administered by the Chester County Conservation District The portion of the grant applicable to the restoration was about $250,000.

One primary question was where to move the channel so that it would be away from the sewer line. We found solid evidence that the stream had actually flowed in the old streambed previously indicated, shown on the next slide, illustrated by a 1972 PENDOT map, shown on the slide following that. It was decided to move the stream back into its original channel.

Where to move the channel?



STREAM COURSE PRIOR TO 1972



Penn DOT Survey ~ 1972

Natural Channel Design In-Stream Devices

We contracted a environmental firm to design and build a natural channel streambed down the old pre-1970 course. The construction required digging out the bed, removing the old maintenance road, as briefly illustrated on the following slide, and stepping the stream down the slope by building the appropriate grade control structures, listed in the table below. The streambed was sized to a appropriate depth and width so that it would carry a one year storm event- about 168 cfs in this reach.   We found out later that the design was for a stream with an average slope of about 2.3%, and probably not appropriate for the 4 to 6% slopes that actually existed.

In-Stream Device	Quantity Installed
Cross Vane	**5**
Double Throated Cross Vane	**4**
J-Hook	**7**
Log Bumps	**8**
Bed Sill	**1**

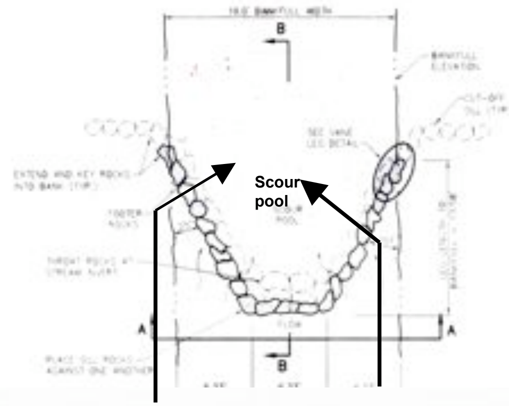
Design Specifications

Bankfull Width = 19 ft   Bankfull Mean Depth = 1.42 ft

Bankfull Discharge = 168 cubic fps

Construction of new reach through the “canyon section” in September 2008

Note that the bottom is still silt, digging did not get down to a gravel base, as did the head cut shown earlier in the reach being abandoned.

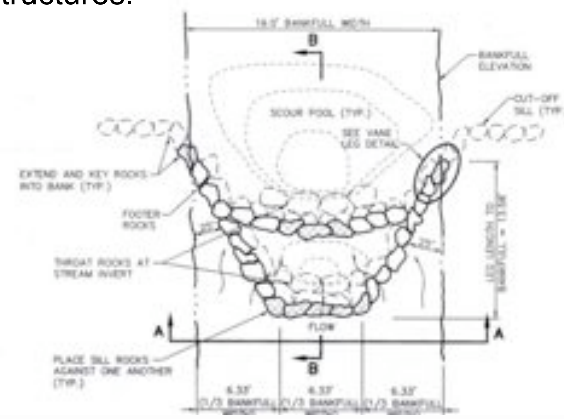


High flow lines

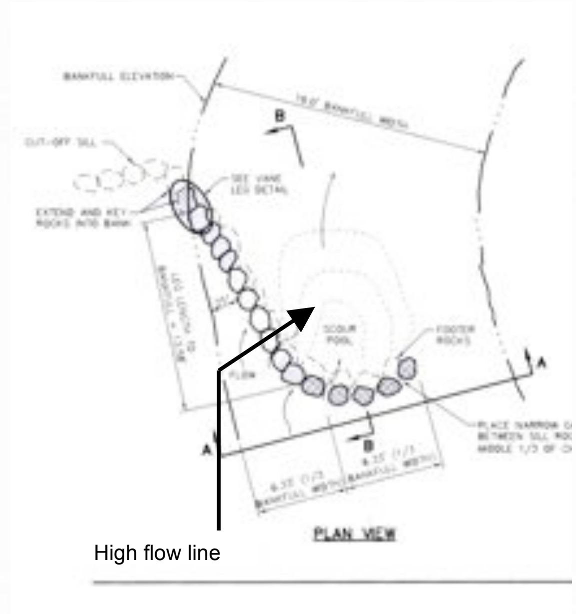
Cross Vane Details

A cross vane is like an immovable headcut- like a waterfall over bedrock- meant to hold the stream elevation above it. It is designed to focus high flows from the edges into the center of the stream, and forms a scour pool with-in the vane as the stream bed is formed. The structure must have a foundation deeper than the scour pool formed. It also must be designed to prevent the water from back-cutting the structure. In addition there are known requirements on how the cross vane should be tied into the bank, throats tied into the arms, the offset of the rocks slightly back from the downstream edge of the underlying row, canting of the boulders up slightly from horizontal, and the % elevation of the arms from horizontal. Many of these requirements were not designed nor built into the structures.

Single throated cross vane



J-Hook Details



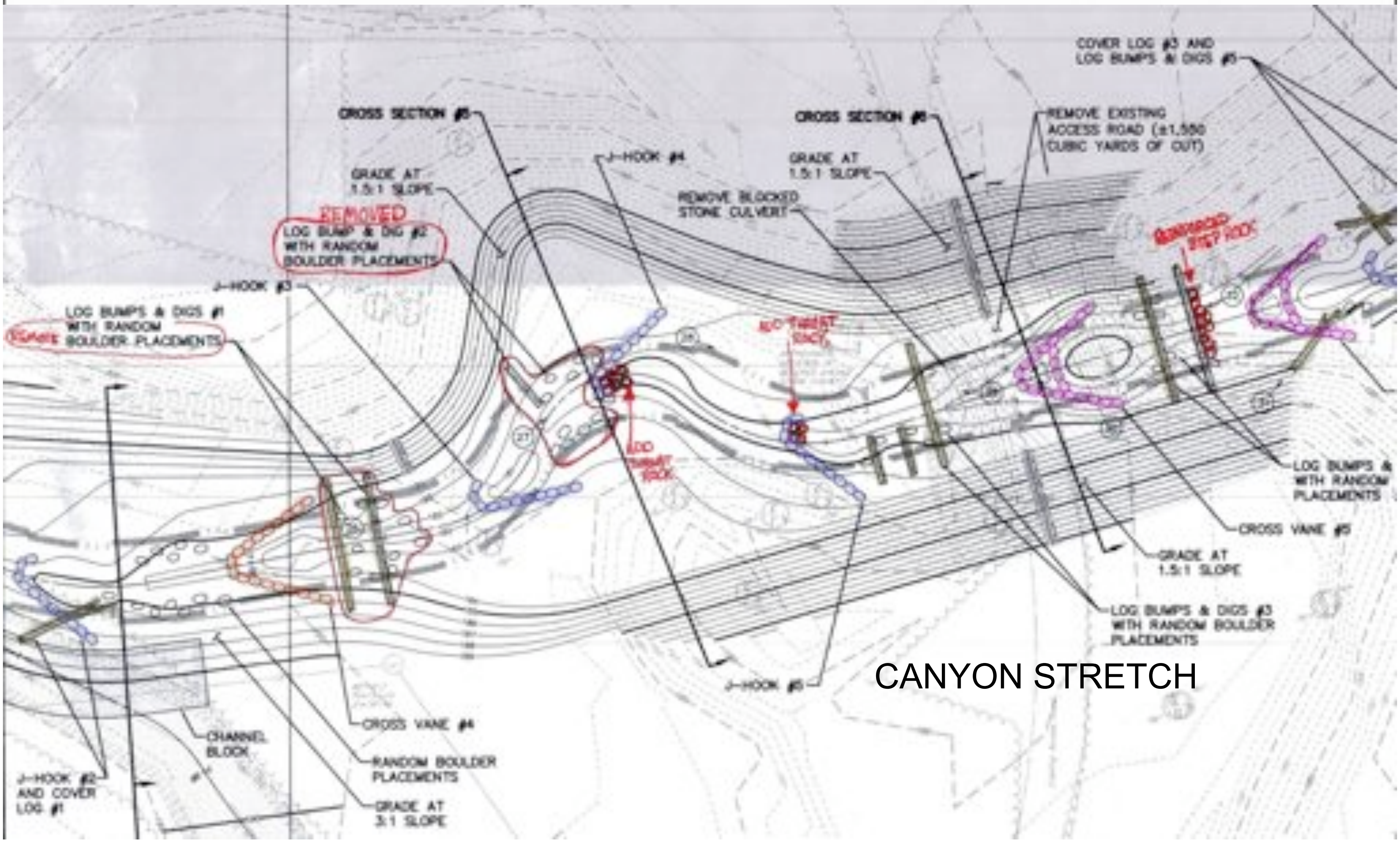
A J-hook helps to hold elevation and diverts flow away from the side of the stream it is on. A scour hole also forms within the hook and the structure footers must be deeper the scour hole formed. It also must be designed to prevent the water from back-cutting the structure.

Log Bump

A log bmp is another form of grade control structure. It must be built to stay wet to prevent wood rot
and be deep enough and be protected on the upstream side to prevent it from being under cut by heavy flows.

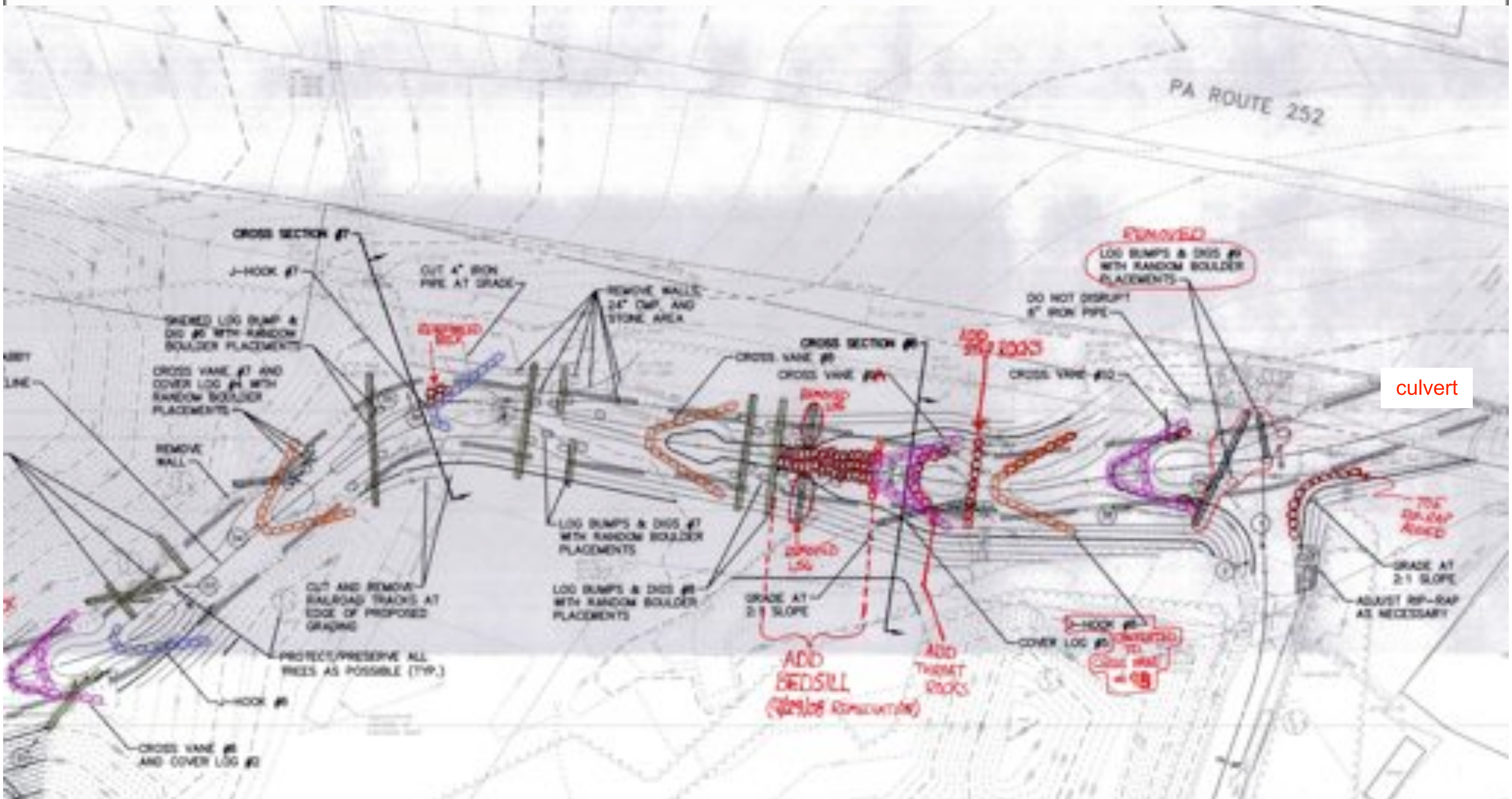
UPPER RELOCATION REACH

This is an elevation contour map of the upper part of the stream reach that was moved, the construction of which was illustrated earlier, showing the location of the stream devices within it to step the stream down the slope- about 4%. The canyon walls are quite steep, confining the stream.

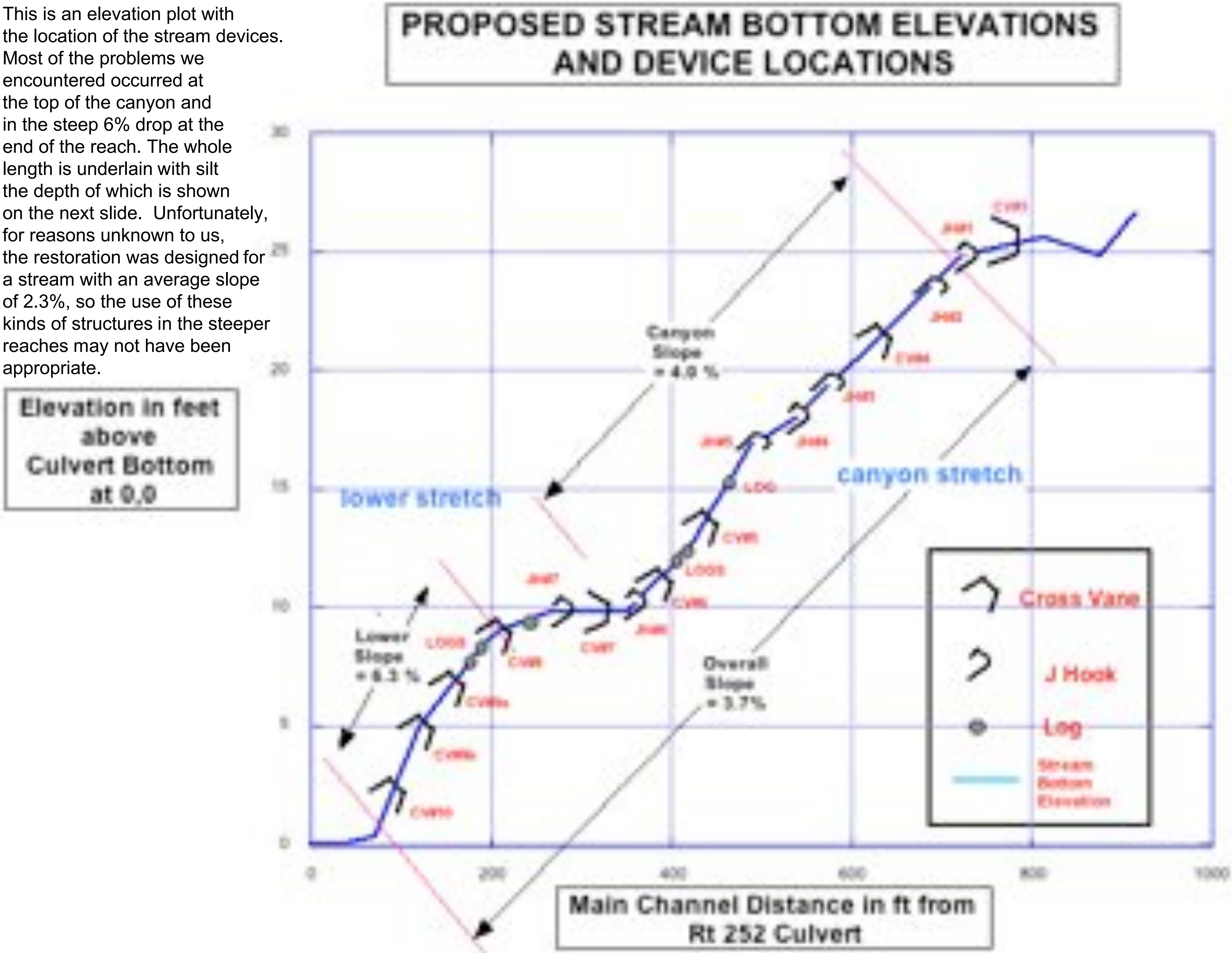


LOWER RELOCATION REACH

This is a contour map of the lower half of the reach and the structures built there. The stream flattens out briefly on the left at the bottom of the canyon, and then drops abruptly at about a 6% slope on the right as it enters the culvert under Route 252. The culvert acts like a concrete grade control structure.



This is an elevation plot with the location of the stream devices. Most of the problems we encountered occurred at the top of the canyon and in the steep 6% drop at the end of the reach. The whole length is underlain with silt the depth of which is shown on the next slide. Unfortunately, for reasons unknown to us, the restoration was designed for a stream with an average slope of 2.3%, so the use of these kinds of structures in the steeper reaches may not have been appropriate.



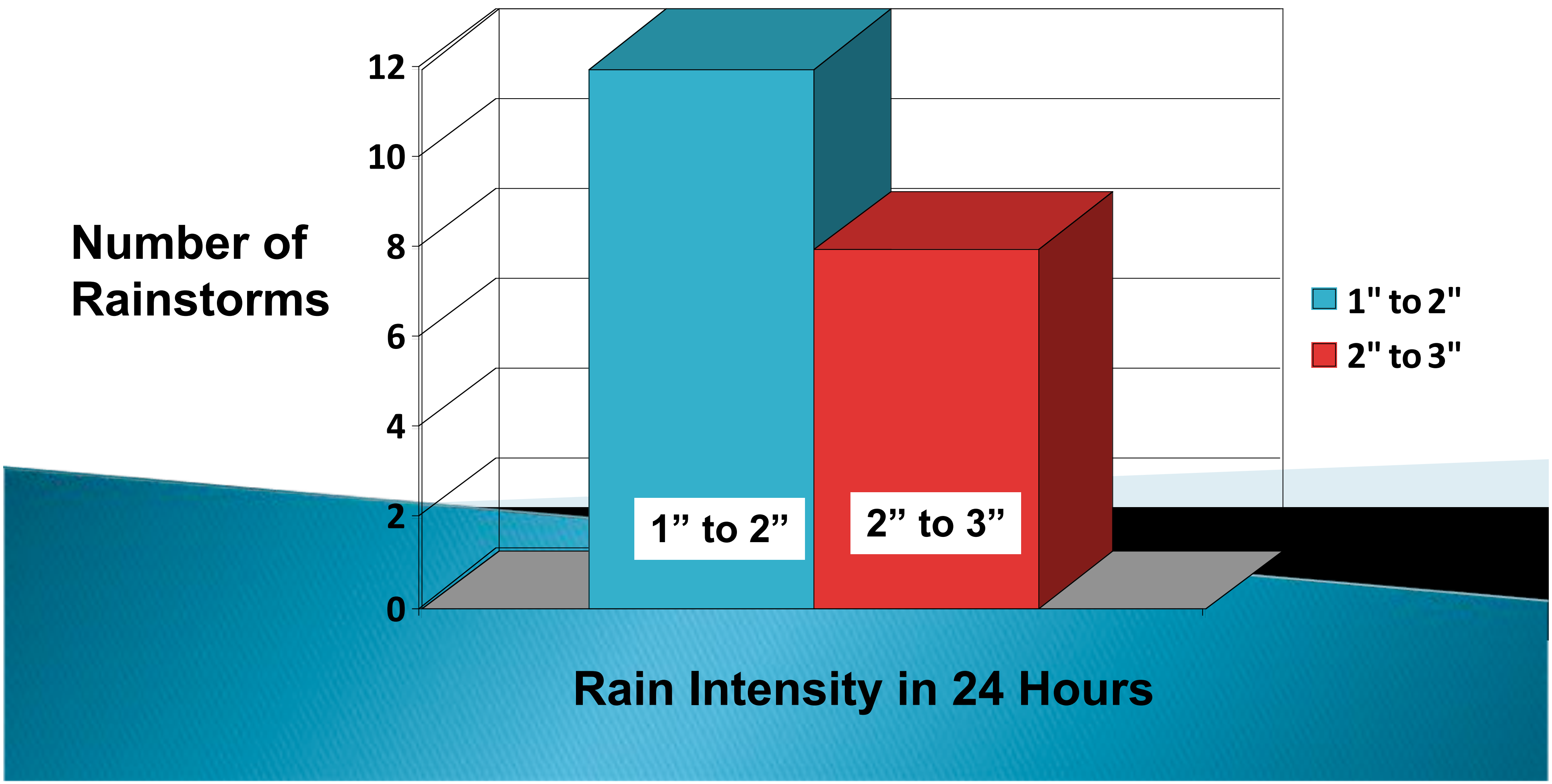
Tile Probe Measurement of Sediment Depth above and Below CV#4

The depth of the silt above and below Cross Vane #4, located at the top of the canyon is shown here- note that below the structure the depth is at least 3 meters! The silt depth was measured for us by Professor Laura Toran and her graduate students of Temple University while they were studying the newly forming hyporheic zone beneath the reach. We later found that the silt was also quite deep at the lower end of the restored reach.

Plot courtesy of Dr. Laura Toran, Temple University

RAINSTORM SIZE AND INTENSITY SEPTEMBER 2008 TO JANUARY 2010

An above average number of significant rainstorms in the 16 months following the completion of the restoration quickly formed the stream channel; problems started to be revealed within 6-9 months. There were 12 storms in the 1”-2” category and 8 in the 2”-3” category; half of the latter were 2 1/2” or more causing 160+ cfs flows. We photographically monitored the structures after heavy storms to document the outcomes. The first of these rainstorms occurred on 9/25 of 2008 and washed out several structures at the lower end of the reach above Rt 252, as illustrated on the next slide. The photos illustrate the depth of silt below the footings of these lower structures, and the nascent headcut that started to move upstream. The structures had to be rebuilt with deeper footers.



Heavy Storm Damage to CROSS VANE #9

9/25/2008 before construction completion

On the following group of slides we illustrate the progression of deterioration of those stream structures which endured the most damage from October 2008 to March 2010.

On the following slide, in Photo #1 Cross Vane #10, a throated cross vane, the last structure in the restored reach, is shown on 3/14/2009 to be intact and holding grade. By 8/2, the throat, which had been built without any footer rocks, nor keyed in to the arms, and without any backing or underlying geo-textile, had washed out, dropping the level of water in the throat and most likely making it impassable for trout, except perhaps at high water. The arrows in Photo#2 point to areas behind the right (facing downstream) wall of the structure which are beginning to be back cut. By 9/142009 two boulders in the right wall were washed out of the structure and by 12/9 three boulders had been moved, and a forming head cut at that point is poised to move upstream.

Cross Vane #10

On the next slide in Photo #1, Cross Vane 9a (a **double** throated vane) is shown intact on April, 2009. This was one of the structures that had been washed out in September of 2008, and rebuilt with deeper footers, but without any underlying or backing geo-textile. By 6/19 the lowest throat had washed out and by 7/29 the center throat followed. The level of the water below the backbone dropped substantially, and high water continued to move rock as shown in photo #4.

Cross Vane #9a

1 4/1/2009

2 6/19/2009

3 7/29/2009

4 1/27/2010

The last log bump on the restored reach, positioned near the top of the final 6% drop, shown in Photo #1 on the next slide, was functioning as of 4/3/2009. Note the heavy bedsill that had been lain on the stream bottom below the log. However, by 6/19 some of the boulders at the foot of the log had washed out and water had begun moving under the the log. By 10/28 the log had been completely undercut and was no longer functioning as a grade control. Several things were wrong with our log bumps. First, the diameter of the logs used were less than the proposed average depth of the stream. Usually, where logs are used in this fashion, they are stacked two deep and pinned with rebar. Second, they should be backed with geotextile to hold the upstream fines in place. It is also important that the log (s) be deep enough into the streambed to that they are continually wet, otherwise the wood will rot prematurely.

Log Bump

J-Hook #3, near the top of the canyon, is shown in Photo #1 on the next slide on 10/14/2008, shortly after it was built. The stream bed had not yet really formed. By 4/3 of 2009 it is clear that the water was trying to move to the outside of the hook. We found that this was the tendency of most of our J-Hooks, probably because the banks could not withstand the high shear stress when the water was moved to the outside of the hook prior to vegetation establishing itself. We tried to move a log into the opening that had been created by the high flow, but it was soon washed out. A deep scour hole was formed in the slot, and sometime after 6/19 the large rockon the end of the hook was rolled into it by high water. This created even more pressure on the opposite bank which became significantly eroded. Eventually we removed the large rock so that water was no longer being forced to outside and the erosion was diminished.

In retrospect, this J-Hook probably should have been placed to force water toward the right bank, away from the high bank on the left . As we found out later, J-Hooks are probably not appropriate structures for a stream reach with this kind of slope.

J-Hook #3

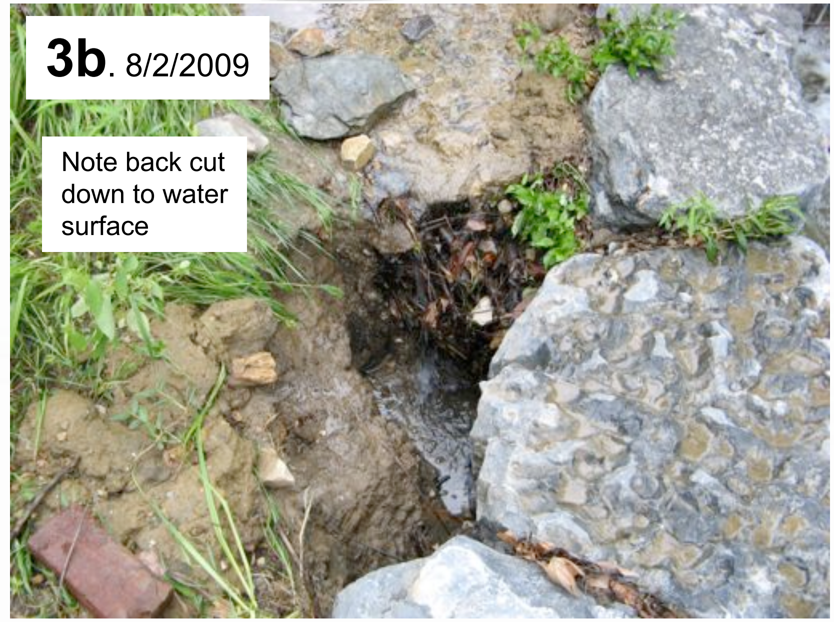
EVOLUTION OF CROSS VANE #4

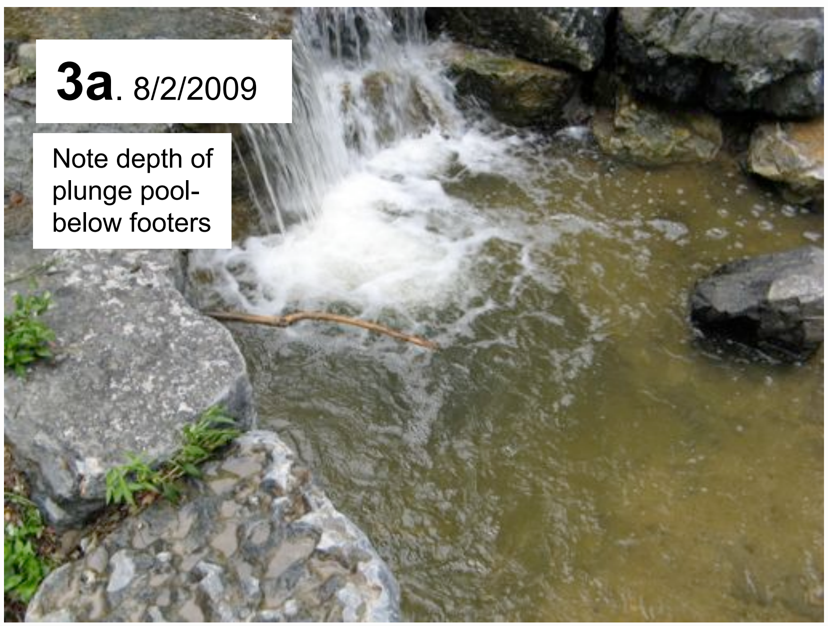
Cross Vane #4, at the top of the canyon, is shown on 10/14/208 shortly after the restoration was completed. The stream channel had not really yet been formed. In an earlier slide we showed that the silt just below Cross Vane #4 was very deep.

By 4/3/2009, a deep plunge pool had formed within the vane and the water drop had become significant. Note that there was already some evidence of back-cutting on the right side of the vane (looking downstream).

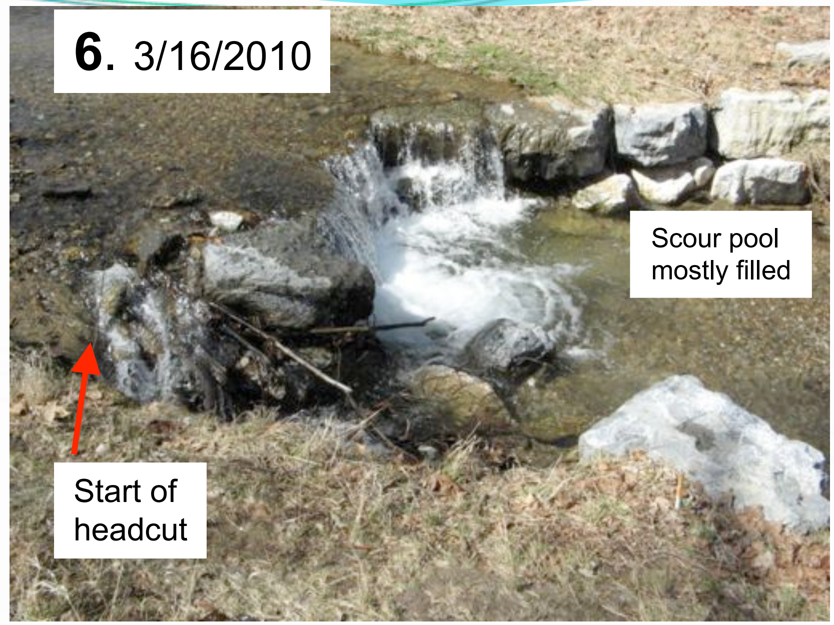
On Photo #3 on the next slide we see that by 8/2 the plunge pool had gotten so deep it was well below the footers of the vane and the back-cutting on the right side was all the way down to the water level in the scour hole. By 10/29 part of the right side of the vane had been collapsed into the scour hole.

EVOLUTION OF CROSS VANE #4



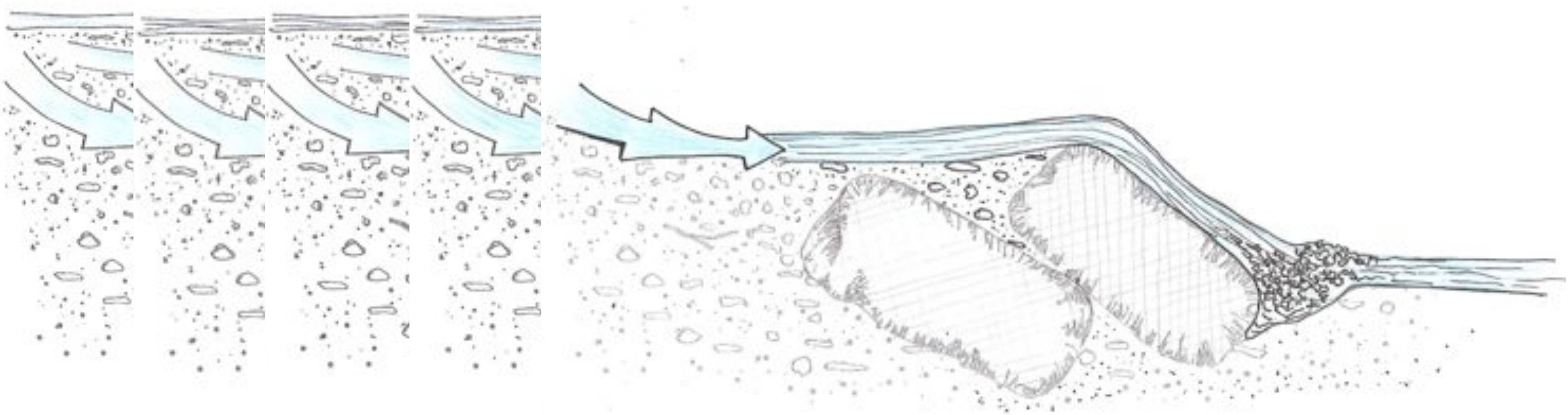


Cross Vane #4 continued



The wall has continued to collapse and a head-cut has formed and started upstream. The debris from the collapse and head cut has nearly filled the deep scour hole.

On the following slide series, we illustrated what we believe is the mechanism of failure. As high water pours over the vane, the scour hole deepens, Similarly, water can erode behind the rocks in the vane and can jet through the openings in the boulders. There was no geo-textile or chinking of these openings with smaller rocks to prevent this jetting. It is standard practice to do at least one or both of these backings on this kind of structure, especially on silt based streams, to prevent just what happened. As the the scour hole gets deeper (there was not rock bottom in the scour hole underlain with geo textile to limit the scour depth), and the back-cutting worsens, heavy water rolls the large rocks into the scour hole and the structure ceases to hold grade and becomes the source of a head cut.



Some Cross Vanes and Log Bumps in the canyon area survived

These structures in the canyon survived into 2010 undamaged, although the log bumps shown on the right below did partially undercut and needed a repair fill on the upstream side. We wonder how long these structures will survive given the inadequate construction.

J-Hook #7 and Cross Vane # 9b also survived intact into 2010

Cross Vane #7, at the bottom of the canyon where the slope abruptly levels and the flood plane widens, is starting to fill in.


January 2010

PROGRESS TOWARDS GOALS

In spite of the problems, we have progressed from the disaster of the old channel on the left, and the potential for an environmental catastrophe if the sewer line had collapsed, to a more controlled high flow through the new channel away from the sewer line, shown on the right. The problem is to now fix the channel with an appropriate design so that the control can be sustained until streamside vegetation can grow and the biological habitat continues to improve.

OLD CHANNEL **NEW CHANNEL**

CONCLUSIONS

Even as our observations of the deteriorating structures of the restoration were progressing we came to the following,conclusions:

1. A sustainable restoration over silt on a 4%-6% slope is a difficult endeavor.
2. Vertical erosion, especially erosion in scour holes below structures is a key issue.
3. Scour outside J Hooks is also important.

More recently, we have consulted at least four noted experts on Natural Channel Design who have separately either walked the restoration site and seen it first hand and/or observed our photographic record of the deterioration. We have elaborated on some of the deficiencies observed on previous slides. Here is general consensus of what they they noted:

1. The design and structures in our restoration are not adequate for stepping a stream down the 4 to 6% slopes that we have in the reach that was moved. Step pool structures would be more appropriate.
2. The foundations on the structures we have are not deep enough for the depth of the anticipated scour holes in the prevailing silt. There was no armoring of the bottom in scour hole areas with appropriately sized rock underlain with geo-textile to attenuate the depth of the scour.
3. No geo-textile or rock chinking was used on the back side of our structures to prevent water from jetting through the openings in walls, exacerbating the back cutting and leading to the collapse of several of them.
4. The vertical rise of the arms on vanes from upstream to down should be in the range of 3 to 7%, and this was specified on the design, but not always followed in the actual construction. The boulders in the walls of the structures were not offset slightly back from the leading edge of the underlying row, and they were not canted slightly upwards on the downstream edge. These are all currently known practices which help to stabilize structures and move the scour hole away from the footers.

Path forward

We are in the process of finding a new designer and contractor with expertise in Natural Channel design with a track record of successful restorations in Piedmont Valley situations with a slope and underlying silt like we have. We need a restoration that will survive the shear stress of the high water levels that Crabby endures, will pass any sediment through the reach without it building and possibly diverting the flow, sufficient streamside vegetation to minimize lateral erosion and eventually shade and cover for the stream, and one that will provides an improved habitat for the fish and insects as the reach is stabilized.

We are seeking funding to carry out a new restoration, which will cost in the neighborhood of $250,000. It may take several years to get the appropriate grants, so in the interim, we hope to proceed with some some emergency repairs to stabilize emerging headcut areas and minimize further streambed deterioration.

At the same time we are proceeding with the infiltration projects up in the Crabby headwaters to decrease the amount of storm water the restoration area has to handle. Monitoring will continue. This work is an on going effort that we expect to see through to a successful model for similar Valley Creek sub-watersheds.

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