MANAGING ROAD SYSTEMS FOR ENVIRONMENTAL PROTECTION AND LONG TERM DURABILITY

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OUTLINE OF ACTIVITIES

DAY 1- CLASSROOM PRESENTATIONS AND EXERCISES

(1) IMPACTS OF ROAD SYSTEMS ON THE LANDSCAPE AND ENVIRONMENT

(2) TYPES OF EROSION

(3) SEDIMENT PRODUCTION VS SEDIMENT DELIVERY

(2) GETTING STARTED

(3) MAKING A LONG-TERM TRANSPORTATION PLAN FOR YOUR ROAD SYSTEM

(4) IDENTIFYING & CHARACTERIZING LOCATIONS WHERE UPGRADING IS REQUIRED

IMPACTS OF ROAD SYSTEMS

ROADS

IMPACTS OF ROAD SYSTEMS

ACCELERATED SEDIMENT DELIVERY

Episodic erosion and sediment delivery (typically a mix of coarse and fines)

Chronic erosion and sediment delivery (typically fine grained sediment)

ALTERED SURFACE AND GROUND WATER HYDROLOGY

Road cutslopes can drain shallow ground water

Road runoff can reduce groundwater recharge

Road runoff can put peaks in the watershed hydrograph

ACCELERATED SEDIMENT DELIVERY FROM ROADS CAN IMPACT DOWNSTREAM BENEFICIAL USES

EPISODIC EROSION AND SEDIMENT DELIVERY- THIS TYPICALLY RESULTS FROM HIGH INTENSITY STORMS THAT CAUSE LOCAL AND REGIONAL STREAM CROSSING WASHOUTS AND LANDSLIDES, THIS TYPE OF EROSION IS RELATIVELY EASY TO IDENTIFY AND IS MANIFEST AS LARGE GULLIES, MAJOR WASHOUTS AND FILLSLOPE MASS WASTING.

CHRONIC EROSION AND SEDIMENT DELIVERY (STEALTH SEDIMENT)- THIS TYPICALLY RESULTS FROM SMALL TO MODERATE RAINFALL EVENTS THAT WASH DUST AND GROUND UP EARTHEN MATERIAL OFF OF THE ROAD SURFACE AND INTO THE STREAMS, IT IS OFTEN HARD TO OBSERVE DURING THE DRY SEASON.

IMPACTS OF ROAD SYSTEMS--EPISODIC EROSION

IMPACTS OF ROAD SYSTEMS--CHRONIC EROSION

IMPACTS OF ROAD SYSTEMS
ALTERED SURFACE AND GROUND WATER HYDROLOGY

IT IS IMPORTANT TO REMEMBER THAT ROADS DON'T ONLY REPRESENT A SOURCE OF ACCELERATED SEDIMENT DELIVERY TO STREAMS THEY ALSO HAVE THE ABILITY TO SIGNIFICANTLY IMPACT WATER RESOURCE AVAILABILITY THROUGHOUT A WATERSHED.

AS AN EXAMPLE: IF A WATERSHED HAS THE FOLLOWING CHARACTERISTICS:

120 MILES OF ROAD THAT IS 12' WIDE

50% OF THE ROADS ARE HYDROLOGICALLY CONNECTED TO THE STREAM NETWORK

IT RECEIVES 96" OF RAINFALL IN A YEAR.

THIS EQUATES TO APPROXIMATELY 227,487,744 GALLONS OF WATER A YEAR BEING ROUTED OFF OF THE LANDSCAPE VIA THE ROAD SYSTEM……

IMPACTS OF ROAD SYSTEMS--EPISODIC EROSION

227,487,744 GALLONS!

LETS PUT THIS WITHIN THE PERSPECTIVE OF FARMING ACTIVITIES

IF A FARMER USES 500,000 GALLONS PER YEAR WATERING THEIR CROP.....

RAINFALL	AMOUNT OF HYDROLOGIC DISCONNECTION TO OFFSET WATER USE
8′ (96″)	694′
4′ (48″)	1,388′
2′ (24″)	2,776

WATERSHED IMPACTS OF ROAD SYSTEMS

EROSION AND SEDIMENT DELIVERY FROM ROAD SYSTEMS

- Increased turbidity- impacts many downstream beneficial uses (impacts fish health, reduces drinking water quality, impacts amphibian health)
- Increased sediment loads- impacts channel geomorphology (reduces channel capacity, increases flooding, causes channel avulsion, impacts fish spawning grounds, simplifies channel geomorphology)
- Increased road maintenance costs

ALTERED SURFACE AND GROUND WATER HYDROLOGY FROM ROAD SYSTEMS

- Can drain shallow ground water (can reduce summer base flows)
- Can put peaks in the winter hydrograph (can cause channel erosion, can increase maximum discharge and stream flow velocities)
- Can reduce ground water recharge (can reduce summer base flows)

IMPACTS OF ROAD SYSTEMS

FINE SEDIMENT IMPACTS ON FISH, THEIR HABITAT AND WATER QUALITY

SPAWNING GRAVEL QUALITY

POOL HABITAT FREQUENCY

POOL DEPTH

INTER-GRAVEL FLOW RATES

EMBEDDEDNESS

FISH GROWTH RATES

QUALITY AND QUANTITY OF FOOD SOURCES

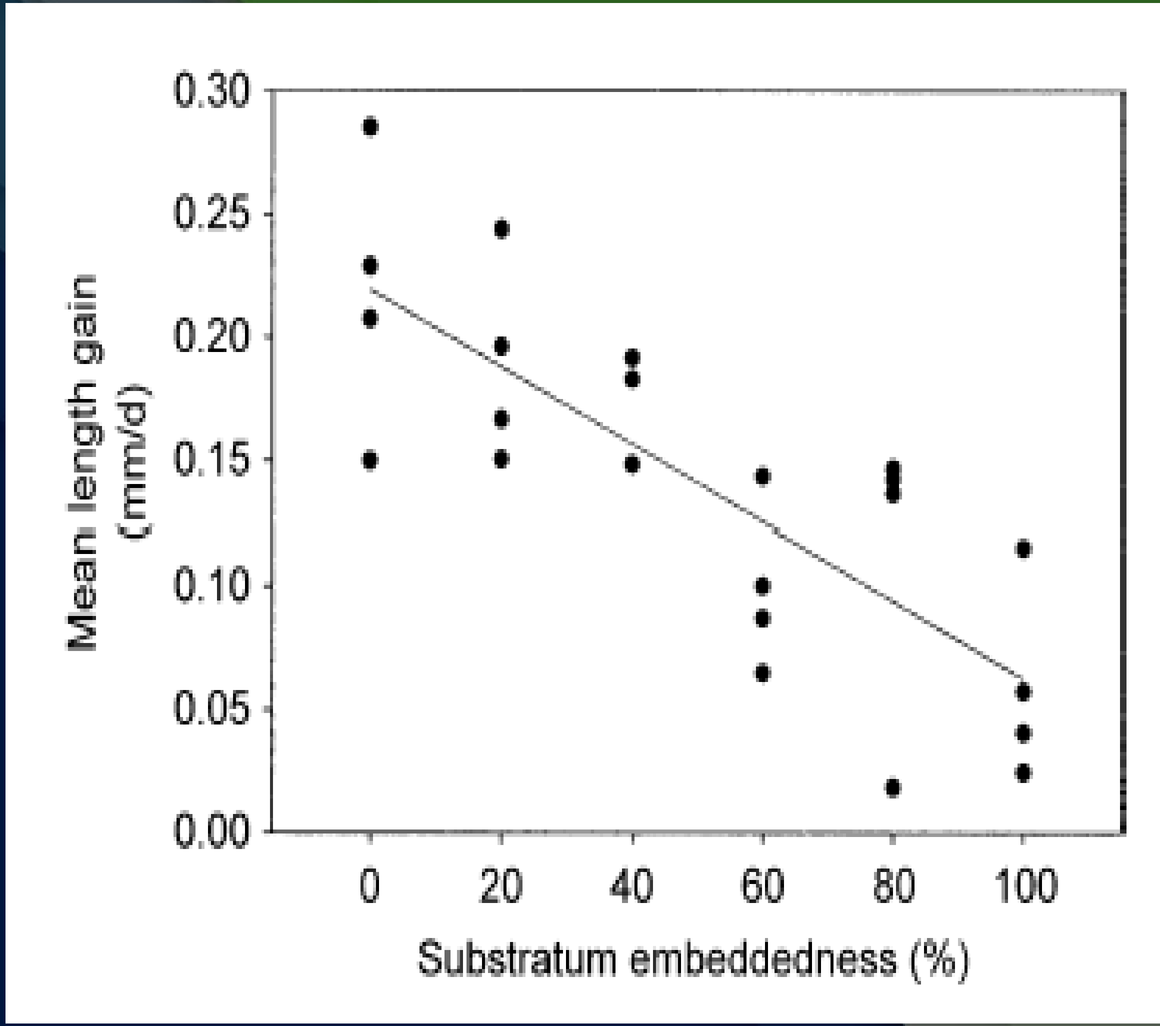
TURBIDITY

AND THERE ARE OTHERS……..

WATERSHED IMPACTS OF ROAD SYSTEMS

TURBID WATER IN AN ANADROMOUS FISH STREAM

WATERSHED IMPACTS OF ROAD SYSTEMS



Impacts on juvenile salmonid growth (Suttle et al., 2004)

IMPACTS OF ROAD SYSTEMS

TURBID WATER IN AN ANADROMOUS FISH STREAM

Sigler et al. (1984) found that turbidity values as low as 25 nephlometric turbidity units (ntu) caused a reduction in juvenile steelhead and coho growth.

High turbidity during winter likely impacts the feeding ability of juvenile salmon, steelhead or cutthroat trout, and the longer the duration of high turbidity the more damage is likely to fish and other aquatic organisms (Newcombe and MacDonald, 1991).

IMPACTS OF ROAD SYSTEMS

TURBID WATER IN AN ANADROMOUS FISH STREAM

All land use activities can play a role in upland erosion and sediment production,

however,

the U.S. EPA, NOAA Fisheries and State Water Quality Control Boards believe "controlling road-related erosion and sediment delivery" is a major necessity to reverse the observed negative trends.

IMPACTS OF ROAD SYSTEMS

LETS CONSIDER TYPICAL BASIN WIDE SEDIMENT SOURCES

CUMULATIVE IMPACTS…AKA (THE TRAGEDY OF THE COMMONS) (DEATH BY A THOUSAND CUTS) (MAULED BY A PACK OF CHIHUAHUAS)

INDIVIDUALS ACTING INDEPENDENTLY AND QUASI-RATIONALLY ACCORDING TO EACH'S SELF-INTEREST BEHAVE CONTRARY TO THE BEST INTERESTS OF THE WHOLE GROUP BY DEPLETING SOME COMMON RESOURCE SUCH AS WATER VOLUME, WATER QUALITY, AND FISHERIES RESOURCES

TYPES OF EROSION

SURFACE EROSION

GULLY EROSION

CHANNEL EROSION

MASS WASTING (LANDSLIDES)

SOIL PEDESTALS (SURFACE EROSION)

GULLY EROSION

CHANNEL EROSION

LANDSLIDES (MASS WASTING)

SEDIMENT PRODUCTION
VERSUS
SEDIMENT DELIVERY

NON-DELIVERING FILLSLOPE LANDSLIDES

WASHED-OUT STREAM CROSSING

SEDIMENT DELIVERY!

CHRONIC ROAD SURFACE RUNOFF

HYDROLOGIC CONNECTIVITY AND SEDIMENT DELIVERY!

CUTBANK SURFACE EROSION

SEDIMENT DELIVERY?

GETTING STARTED

(1) PROCURE HIGH RESOLUTION TOPOGRAPHY OF YOUR AREA THAT INCLUDES YOUR ROAD SYSTEM

(2) MAKE A LONG-TERM TRANSPORTATION PLAN FOR THE ROAD SYSTEM

(3) IDENTIFY YOUR DESIGN VEHICLE FOR EACH ROAD

(4) DETERMINE THE APPROPRIATE DESIRED FUTURE CONDITIONS FOR EACH ROAD

GETTING STARTED

PROCURE A BASE MAP THAT YOU CAN USE TO MAP THE ROAD NETWORK FOR YOUR PROJECT…

PROCURE THE HIGHEST RESOLUTION TOPOGRAPHY AND/OR AIR PHOTOS OF YOUR PROPERTY YOU CAN FIND

PREFERRED OPTION: LIDAR IS THE INDUSTRY STANDARD, IT DOES NOT COVER EVERYWHERE IN CALIFORNIA…..

IF AVAILABLE, IT CAN BE DOWNLOADED FROM: HTTPS://APPS.NATIONALMAP.GOV/DOWNLOADER/

SECONDARY OPTION: HIGH RESOLUTION NAIP IMAGERY OR AIR PHOTOS, COVERAGE AVAILABLE FOR ALL OF CALIFORNIA

NAIP IMAGERY CAN BE PROCURED FROM: HTTPS://DATAGATEWAY.NRCS.USDA.GOV/GDGHOME_DIRECTDOWNLOAD.ASPX

AIR PHOTOS CAN BE PROCURED FROM THE CALIFORNIA GEOLOGIC SURVEY IN YOUR LOCAL NEIGHBORHOOD

TERTIARY OPTION: *USGS 7.5' TOPOGRAPHIC MAPS, COVERAGE AVAILABLE FOR ALL OF CALIFORNIA*

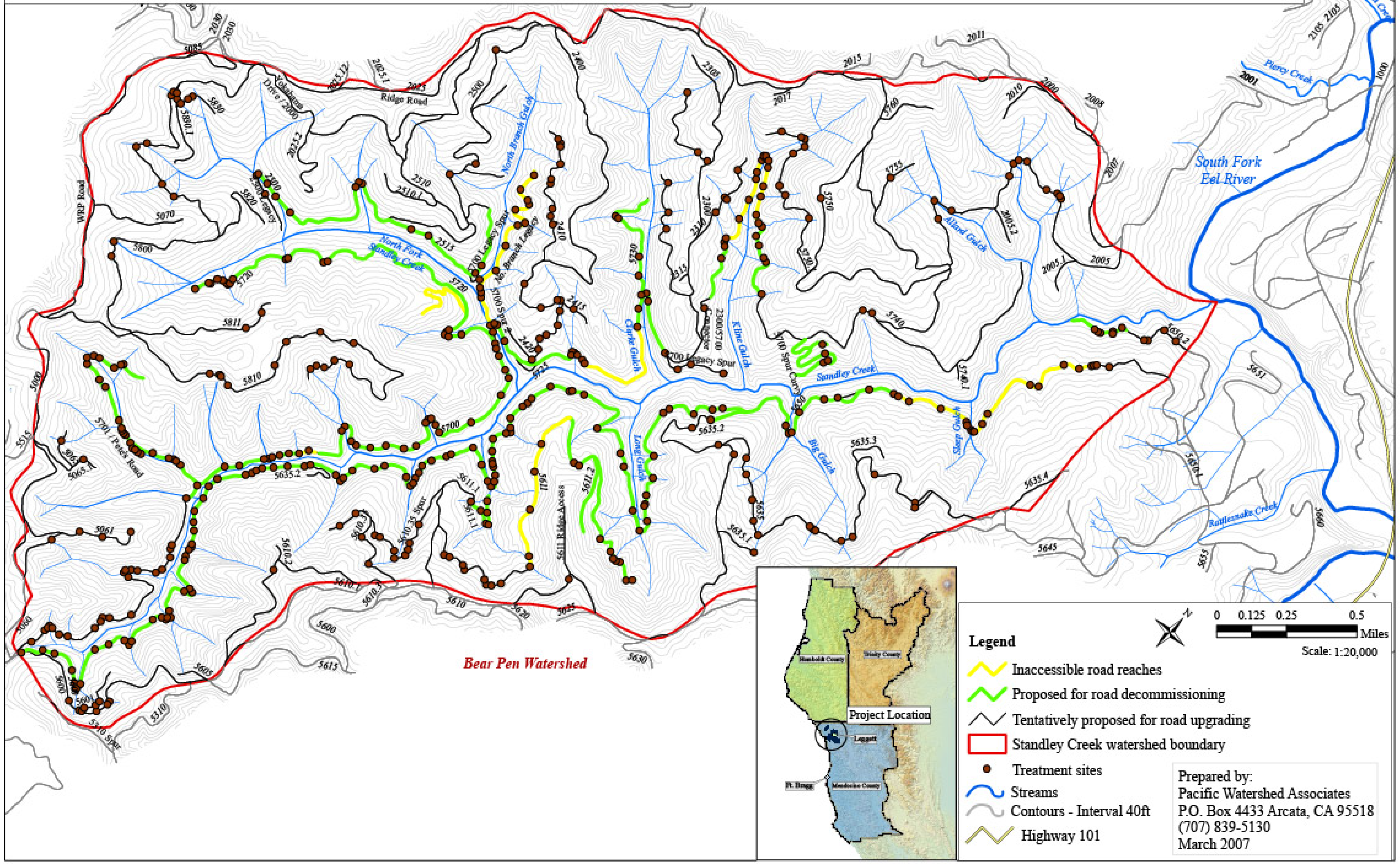
USGS TOPOGRAPHIC MAPS CAN BE DOWNLOADED AT:

HTTPS://WWW.USGS.GOV/PROGRAMS/NATIONAL-GEOSPATIAL-PROGRAM/TOPOGRAPHIC-MAPS

GETTING STARTED

MAKE A LONG-TERM TRANSPORTATION PLAN FOR THE ROAD SYSTEM

Figure 10. Preliminary long term transportation plan and desired future condition for the Standley Creek road network, Standley/Hollow Tree Creek Watershed Assessment, Mendocino County, California.



GETTING GOING

OK,

YOU HAVE YOUR BASE MAP….

YOU HAVE A GENERAL INFRASTRUCTURE PLAN THAT INFORMS FUTURE ROAD USES

YOU HAVE IDENTIFIED YOUR DESIGN VEHICLE THAT WILL PUT SIDEBARS ON YOUR DESIGNS

AND YOU HAVE A GENERAL STRATEGY FOR PRESCRIBING ROAD TREATMENTS

SO NOW ITS TIME TO GET IN THE FIELD AND

(1) CHARACTERIZE THE EXISTING ROAD AND STREAM CROSSING CONDITIONS

(2) PRESCRIBE TREATMENTS TO TREAT THE ROAD

GETTING GOING

A FEW POINTERS TO GET GOING

(1) WORK FROM THE TOP OF THE WATERSHED DOWN WHEN INVENTORYING ROADS.

THIS WILL HELP YOU IDENTIFY AND TRACE EROSION FEATURES AS THEY CROSS SEVERAL ROADS, WHICH WILL IN TURN HELP YOU DEVELOP TREATMENT PRESCRIPTIONS FOR COMPLEX EROSIONAL FEATURES

(2) SEPARATE ENVIRONMENTAL PROTECTION TREATMENTS AND MAINTENANCE TREATMENTS

(3) MAP THE ROAD RUNOFF FLOW PATHS

(4) BE MINDFUL OF THE LUMPER / SPLITTER QUANDARY

(5) IGNORE TEMPORARY OR DYSFUNCTIONAL ROAD DRAINAGE FEATURES AS THEY ARE EPHEMERAL ON THE LANDSCAPE AND ARE NOT A LONG-TERM SOLUTION FOR UPGRADED AND MAINTAINED ROADS.....EXAMPLE....WATERBARS....

ROAD SURFACE PROBLEMS AND TREATMENTS

ROAD SURFACE PROBLEMS AND TREATMENTS

SO NOW YOU ARE GOING TO TRAVERSE THE ROAD, IDENTIFY EROSIONAL FEATURES, AND DETERMINE IF THE ROAD SURFACE IS HYDROLOGICALLY CONNECTED TO THE STREAM SYSTEM……

EVERY LOCATION WHERE THE ROAD SURFACE IS HYDROLOGICALLY CONNECTED TO THE STREAM SYSTEM BECOMES A SITE THAT REQUIRES A TREATMENT PRESCRIPTION (ENVIRONMENTAL PROTECTION TREATMENTS)….

IF THE ROAD EXHIBITS EROSIONAL FEATURES BUT THE RUNOFF IS NOT CONNECTED TO THE STREAM SYSTEM, YOU CAN PRESCRIBE A TREATMENT TO IMPROVE THE DRIVABILITY BUT THIS ACTION HAS LESS ENVIRONMENTAL BENEFITS….

IF YOU ARE ON A LIMITED BUDGET OR ARE CONSIDERING APPLYING FOR A GRANT TO IMPROVE ENVIRONMENTAL CONDITIONS, PRIORITIZE THE ACTIONS THAT HAVE ENVIRONMENTAL BENEFITS……

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

POTHOLES

CAUSES:

FLAT ROAD SURFACE

POOR ROAD DRAINAGE

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD RILLING

CAUSES:
LACK OF ROAD DRAINAGE DISCHARGE POINTS

RUN ON FROM HILLSLOPE

RUN OF FROM OTHER ROADS

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD RILLING

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

RUN ON FROM HILLSLOPE

RUN OF FROM OTHER ROADS

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD RILLING

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

RUN ON FROM HILLSLOPE

RUN OF FROM OTHER ROADS

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD GULLYING

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

RUN ON FROM HILLSLOPE

RUN OF FROM OTHER ROADS

POOR ROAD LOCATION

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD GULLYING

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

RUN ON FROM HILLSLOPE

RUN OF FROM OTHER ROADS

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD RUTTING

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

VEHICLE TRAFFIC IN WET WEATHER CONDITIONS

LACK OF ROAD SURFACING

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD RUTTING

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

VEHICLE TRAFFIC IN WET WEATHER CONDITIONS

LACK OF ROAD SURFACING

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

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VEHICLE TRAFFIC IN WET WEATHER CONDITIONS

LACK OF ROAD SURFACING

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD SURFACE EROSION

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

EXCESSIVE VEHICLE TRAFFIC

LACK OF MAINTENANCE

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD SURFACE EROSION

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

EXCESSIVE VEHICLE TRAFFIC

LACK OF MAINTENANCE

LACK OF ROAD SURFACING

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

ROAD SURFACE EROSION

CAUSES:

LACK OF ROAD DRAINAGE DISCHARGE POINTS

EXCESSIVE VEHICLE TRAFFIC

LACK OF MAINTENANCE

LACK OF ROAD SURFACING

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

Road surfaces and eroding cutbanks feed active ditches…

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

CUTBANK AND DITCH EROSION

CAUSES:
GRADING MAINTENENCE

SURFACE EROSION FROM RAINFALL

HILLSLOPE RUN ON

LANDSLIDES

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

CUTBANK AND DITCH EROSION

SIGNS OF SEDIMENT TRANSPORT IN A DITCH

THIS SEDIMENT MUST COME FROM SOMEWHERE

ROAD SURFACE PROBLEMS AND TREATMENTS
TYPICAL EROSIONAL FEATURES

CUTBANK AND DITCH EROSION

CAUSES OF DITCH EROSION:

DIVERTED STREAM

EXCESSIVE ROAD RUNOFF

RUN ON FROM HILLSIDE OR UPHILL ROAD

ROAD SURFACE DISCHARGE POINTS, OR LACK THEREOF
TYPICAL EROSIONAL FEATURES

HILLSIDE GULLY AT DISCHARGE LOCATION

CAUSES:
EXCESSIVE ROAD RUNOFF (LACK OF ROAD SURFACE DRAINAGE FEATURES)

DIVERTED STREAM

ERODIBLE HILLSIDE

ROAD SURFACE DISCHARGE POINTS, OR LACK THEREOF
TYPICAL EROSIONAL FEATURES

HILLSIDE GULLY AT DISCHARGE LOCATION

CAUSES:
EXCESSIVE ROAD RUNOFF (LACK OF ROAD SURFACE DRAINAGE FEATURES)

DIVERTED STREAM

ERODIBLE HILLSIDE

ROAD SURFACE DISCHARGE POINTS, OR LACK THEREOF
TYPICAL EROSIONAL FEATURES

HILLSIDE GULLY AT DISCHARGE LOCATION

CAUSES:
EXCESSIVE ROAD RUNOFF (LACK OF ROAD SURFACE DRAINAGE FEATURES)

DIVERTED STREAM

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HILLSIDE GULLY AT DISCHARGE LOCATION

CAUSES:
EXCESSIVE ROAD RUNOFF (LACK OF ROAD SURFACE DRAINAGE FEATURES)

DIVERTED STREAM

ERODIBLE HILLSIDE

ROAD CONFIGURATIONS THAT LEAD TO INCREASED EROSION AND SEDIMENT DELIVERY

INSLOPED ROAD WITH DITCH AND BERM

ROAD CONFIGURATIONS THAT LEAD TO INCREASED EROSION AND SEDIMENT DELIVERY

OUTSLOPED ROAD WITH SMALL BERM

ROAD CONFIGURATIONS THAT LEAD TO INCREASED EROSION AND SEDIMENT DELIVERY

FLAT ROAD WITH SIDECAST BERM

ROAD CONFIGURATIONS THAT LEAD TO INCREASED EROSION AND SEDIMENT DELIVERY

THROUGH-CUT ROAD

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff feeding into a small stream

Connected!

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff feeding into a small stream

Connected!

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff feeding into a small stream

Connected!

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff crossing the hillside and feeding into a small stream

Connected!

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff feeding into a small stream

Connected!

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff crossing the hillside and feeding into a small stream

Connected!

Note: there is not a lot of gully erosion at this location

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff directed into a small stream

Connected!

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff directed into a small stream

Connected!

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff directed into a small stream

Connected!

Note: Classic engineering, insloped road with a ditch

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Road runoff directed into a small stream

Connected!

Note: ditch flow cleaner than stream flow

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

Sediment delivery occurs where the road prism, including road surfaces and ditches, are “hydrologically connected” to stream channels

DETERMINING HYDROLOGIC CONNECTIVITY BETWEEN THE ROAD AND THE STREAM SYSTEMS

What to look for… *(identifying hydrologic connectivity)*

- Road surface and/or ditch draining into or leading to a stream crossing drainage structure inlet or outlet;
- Evidence of surface flow between the drainage structure outlet and a natural stream channel/flood prone area;
- A channel or gully that extends from a road drainage structure outlet to the high water line of a defined channel or a flood prone area;
- A sediment deposit that reaches the high water line of a defined channel or a flood prone area;
- Observation of turbid water reaching the watercourse during runoff events; or
- Indications of channel widening and/or incision below a drainage structure resulting from increases in flow.

Quantifying Chronic Road Surface Erosion

Road width x road length x decadal surface lowering rate = Erosion volume over next 10 years

Decadal erosion volume x percent of material that delivers to stream = Future sediment delivery

Example: 100' of road that is 15' wide flows to a rolling dip. You estimate the road is lowering at a rate of .2' / decade. At the outlet of the rolling dip there is evidence that some of the sediment is settling out on the hillside in a grass thicket. There is also evidence that some of the sediment is being routed to a proximal stream via a raw, vertical banked, active gully with dimensions 50'L x 1.5'w x 1'd. (you estimate 50% of the sediment is delivered to a stream).

What is your expected future sediment delivery over the next decade? Consider everything!

100' x 15' = 1,500 sq. ft. of road surface area

1,500 sq. ft. x .2' of surface lowering per decade = 300 cu. ft./decade

300 cu. ft. x 50% sediment delivery = **150 cu. Ft./ decade = 5.5 cu. Yds.**

Are we forgetting anything?

Quantifying Chronic Road Surface Erosion

What are we forgetting……..the gully…..

The gully is showing evidence that it is active and has the potential to enlarge.
How do we estimate the future enlargement of the gully?…….We estimate future enlargement of the gully

This is a subjective call, like many of the calls you will be required to make, what is important in this process is consistency not necessarily accuracy.

Criteria you should be considering:
How vulnerable to erosion is the hillside?
Is it revegetating?
Will the gully enlarge under existing conditions? Will it simply lay back to stable sideslopes?

You will need to make a series of scientific, defendable observations to support your call…..There is no right or wrong answer because were making a guess founded in a scientific process.

Keep in mind, you have never seen a 100-year return interval rainfall event, but its fair to say a biblical scale event like that would likely result in significant erosion, even under some of the most stable conditions.

Quantifying Chronic Road Surface Erosion

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Features to quantify when estimating future road surface related erosion…

Road surface erosion
Cutslope surface erosion
Ditch erosion
Gully erosion

Prioritizing Road Surface Treatments

Prioritizing any suite of treatment prescriptions relies on two primary field observations:

(1) The likelihood of the erosion to occur (Erosion Potential)

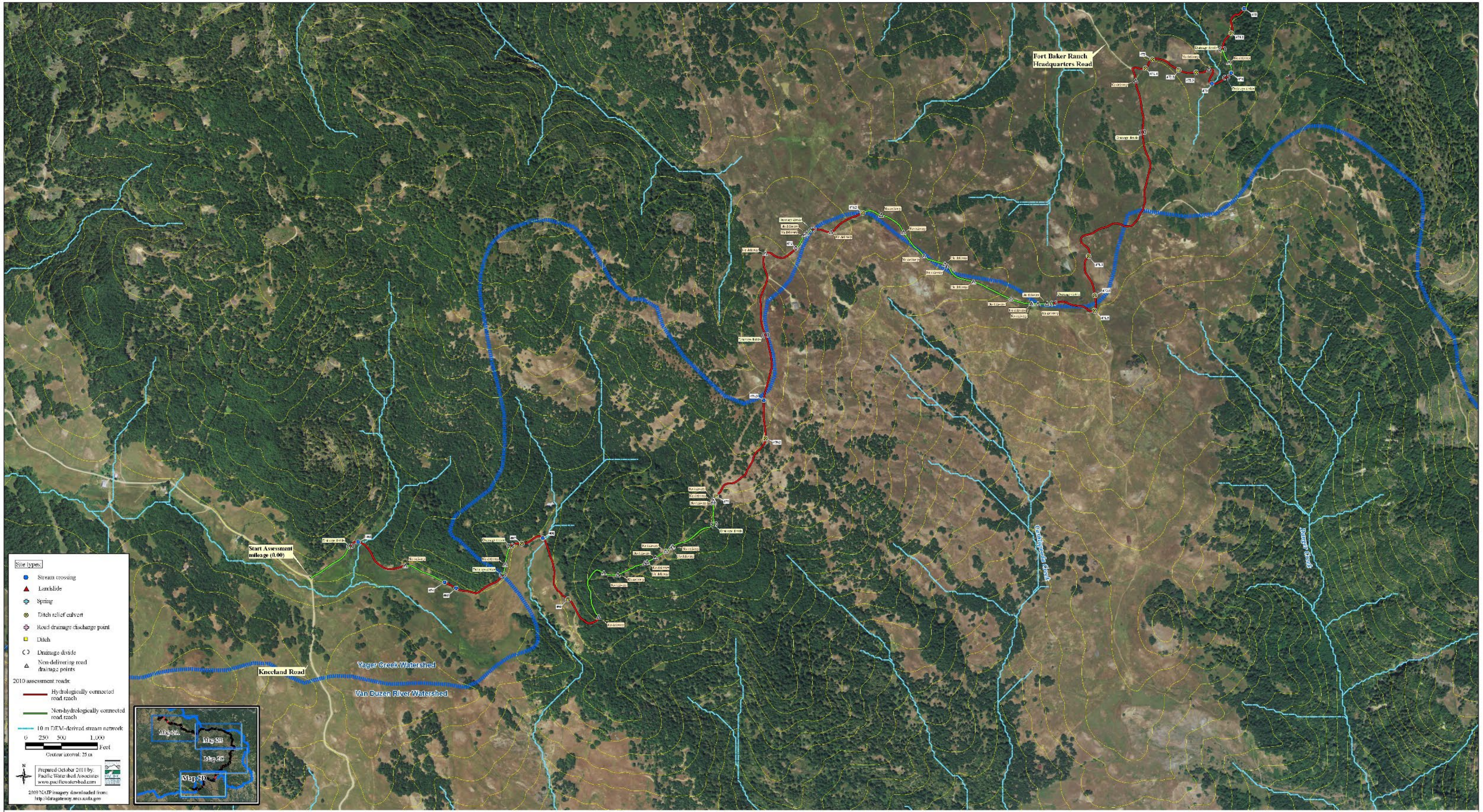
Criteria you should be considering:
How vulnerable to erosion is the hillside?
Is it revegetating?
Will the gully enlarge under existing conditions?
Will it simply lay back to stable sideslopes?

(2) The expected magnitude of future erosion (Future Potential Delivery volume)

More often than not, the individual treatment priorities for your sites will be relative to the other sites Within your project area.

The cumulative suite of treatment priorities and expected future sediment delivery for your project area can be used to prioritize several areas within the greater project area or compare to other regional projects.

Typical PWA road surface connectivity map



Map 2d. Inventoried sites by problem type in the southern project area, Showers Pass Road Sediment Source Assessment, Humboldt County, California.

TREATMENT STRATAGIES FOR ROAD RELATED EROSION AND SEDIMENT DELIVERY

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

There's a time and place for everything, but there some bad ideas out there also……

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Questions you should be asking yourself as you evaluate your road upgrade and maintenance plans

(1) Have you identified all of the locations where the road surface is hydrologically connected to the stream system?
(2) Are the initial treatment prescriptions based on site specific conditions and are they appropriate to minimize, to the extent possible, hydrologic connectivity and sediment delivery? Think performance based not prescriptive based
(3) In locations where hydrologic connectivity is unavoidable (such as the final approach to a stream crossing), have you prescribed road surfacing material (such as road rock) to minimize sediment production from the road surface?
(4) Have you developed a science based, property wide, prioritized action plan to address hydrologic connectivity between the road and the stream network?
(5) Do you have a thorough monitoring and adaptive management plan and is it being implemented?
(6) Does your road management plan include designating which roads are seasonal and which are for year round use?
(7) Do you or your consultant appear to have the mental and financial capacity to actively manage your road systems?

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

What is wrong with this conversation?

Tom—"What condition would you consider your ranch road system to be in"?

Landowner—"Our roads are in great condition, we grade them every year"……

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

What is wrong with this conversation? DISCUSSION

The issue here is that the landowner is focusing on drivability and not environmental protection……They view a good road as one that does not inhibit their intended use for it, without regard to the level of environmental protection is provides……This is not uncommon and can be addressed with a little education….

Typically if a landowner says something like this to me I say…. "if your road systems were in great condition you wouldn't need to grade them every year"

The reality is, an environmentally protective road is also usually a low maintenance road…

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Treat the cause of the problem, not the symptom

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Treating the symptom of a problem

The problem is there is too much water on the road, the symptom is a gully has formed, here they are trying to stabilize the gully

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

DRC gully…a symptom

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Symptomatic gully…

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

…Symptomatic treatment

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Jahnsian Steps to Geologic Safety
Remember…keep it scientific

1. **Recognition** of local erosional features
2. **Characterization** of the erosional features
3. **Assessment** of the risk posed by the features
4. **Mitigation** of the erosion and sediment delivery

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ANALYSIS OF CONNECTIVITY AND SEDIMENT DELIVERY FROM THE ROAD SYSTEM

Ideally, the characteristics of each road surface discharge point is entered into a database and integrated into a GIS format for quantitative and spatial analysis

This will allow the landowner to:

(1) Spatially visualize the condition their road system is in
(2) Identify specific problematic spots or road reaches on their property
(3) Estimate upgrade costs and logistics requirements
(4) Develop a prioritized treatment schedule
(5) Identify areas of increased monitoring requirements

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Mitigation objectives road drainage effectiveness

A road drainage system must satisfy two main criteria if it is to be effective throughout its design life:

1) It must allow for a minimum of disturbance of the natural drainage pattern.
2) It must drain surface and subsurface water away from the roadway and dissipate it in a way that prevents excessive collection of water in unstable areas and subsequent downstream erosion.

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Mitigation tools for hydrologically connected road surfaces

What tools and techniques are available and pertinent for the site specific discharge point?

Road shaping (can significantly reduce contributing road surface area and effectively disperse road runoff)
Adding or improving road drainage infrastructure (encourages water dispersion and infiltration)
Road and or ditch surfacing (reduces erosion potential of the road surface)
Sediment control (captures and retains in-transport sediment)
Road Realignment (moves road to preferable location)

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Mitigation strategies for hydrologically connected road surfaces

Effective and environmentally friendly road drainage treatments should be designed to allow road runoff to disperse and infiltrate on the native hillside

Road drainage improvements that collect and concentrate runoff are inherently more likely to result in hydrologic connectivity between the road and stream network

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Mitigation strategies for treating connectivity

1) Install a “disconnecting” drainage facility or structure “close” to the watercourse crossing;
2) Increase the frequency of ditch relief culverts for connected roads with inside ditches;
3) Eliminate existing ditch relief culverts with connected gullies
4) Convert crowned or insloped roads with inside ditches, to outsloped roads with rolling dips;
5) Remove or breach outside berms on crowned or outsloped roads if they result in connectivity;
6) Avoid discharging concentrated runoff onto unstable areas.

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

It is important to develop a road surface upgrade plan that is consistent with local environmental conditions, expected use levels, and other constraints.
"Safety-Performance-Protection"

Keep in mind that there are a lot of tools and techniques available to landowners, the ones they employ should be the ones that perform best given the characteristics of each road segment and discharge point while considering other constraints

As an example: the gold standard geometry and drainage for many roads may be outsloping with frequent rolling dips but this may not be practical for roads in the snow zone (safety) or for steeper road grades where the design vehicle may be a lowbed truck (access)

Similarly, outsloping may be a great choice for the geometry of a road system, but it still may not be a good idea on a turn where momentum may carry a vehicle off of the road

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Have a “high quality” monitoring and adaptive management plan for road surface maintenance…..and implement it

Its important to implement a road surface upgrade plan that is based on scientific analysis and Best Management Practices but it is just as important to develop a monitoring and adaptive management plan that identifies and treats weak spots in your original plan…..

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Treat the cause and not the symptom of a problem

remember……every complex problem has a simple solution that doesn't work

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Gullies from road surface runoff

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Another gully !!!?

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Treating the cause by dispersing road runoff

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Road drainage performance is more important than meeting prescriptive recommendations

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Hydrologic connectivity is treated by road surface shaping and the installation of road surface and ditch drainage structures

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

- Connected stream crossing approaches (road shape, berms, relief culverts, rolling dips, and road surfacing)
- Ditch drainage structures (ditch relief culverts, rolling dips, sediment basins)
- Road shaping (insloped, crowned, outsloped)
- Road surface drainage structures (road dips, rolling dips, waterbars and rubber waterbars, open top box culverts, berms, critical dips)
- Leadout ditches (for switchbacks, crowned roads, through cuts, fall line roads)
- Berm removal and berm breaks
- Abandonment treatments (ripping, cross road drains, outsloping, crossing excavation, fillslope excavation)

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

"Hydrologic invisibility"

The goal is to have the road only minimally affect the water's "natural, pre-road" flow path on the hillslope.....

Water encounters the road via:

- Rainfall and surface flow from the roadbed and cutbank
- Shallow subsurface flow from the cutbanks
- Streamflow at stream crossings

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ROAD
DRAINAGE
TREATMENTS

Road shaping

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Outsloping and conforming to the topography

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Free draining, outsloped roads

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Before

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

After

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Before

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

During

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Before

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

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Before

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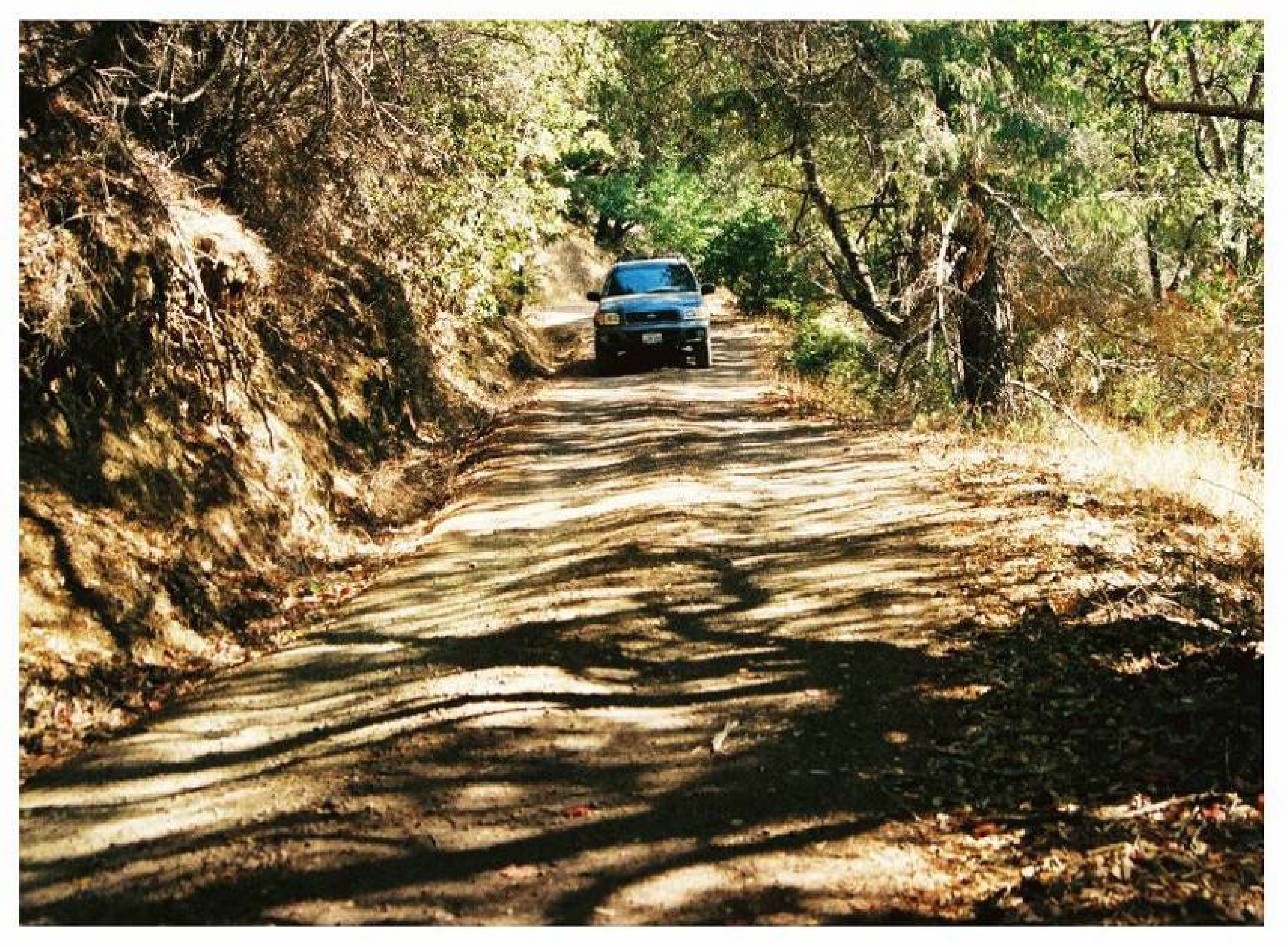
After

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY



Before

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

After

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Before

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

After

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Outsloped with ditch

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Driveability, Functionality and Safety

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ROAD DRAINAGE STRUCTURES

Rolling dips, ditch relief culverts and berm breaks

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Road with rolling grade

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Outsloped, rolling dip and inside ditch

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Outsloped with abrupt rolling dip

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Outsloped with rolling dips

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Outsloped with rolling dips

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Ranch road - Before

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

After

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Rolling dip construction using ripping cat

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Rolling dip: watering for compaction

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Rolling dip: rolling for compaction

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Functional, drivable and safe

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Berms

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Draining through-cuts

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Berm breaks

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Drainage cut-out drains road rut

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Berm breaks

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Controlling erosion and sediment in ditches

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Silt fence ditch filter

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Sediment storage on vegetated flat

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Sediment basin under construction

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Sediment basin

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Roadside sediment retention basin

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Roadside sediment retention basin

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Sediment basin drainage outlet

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

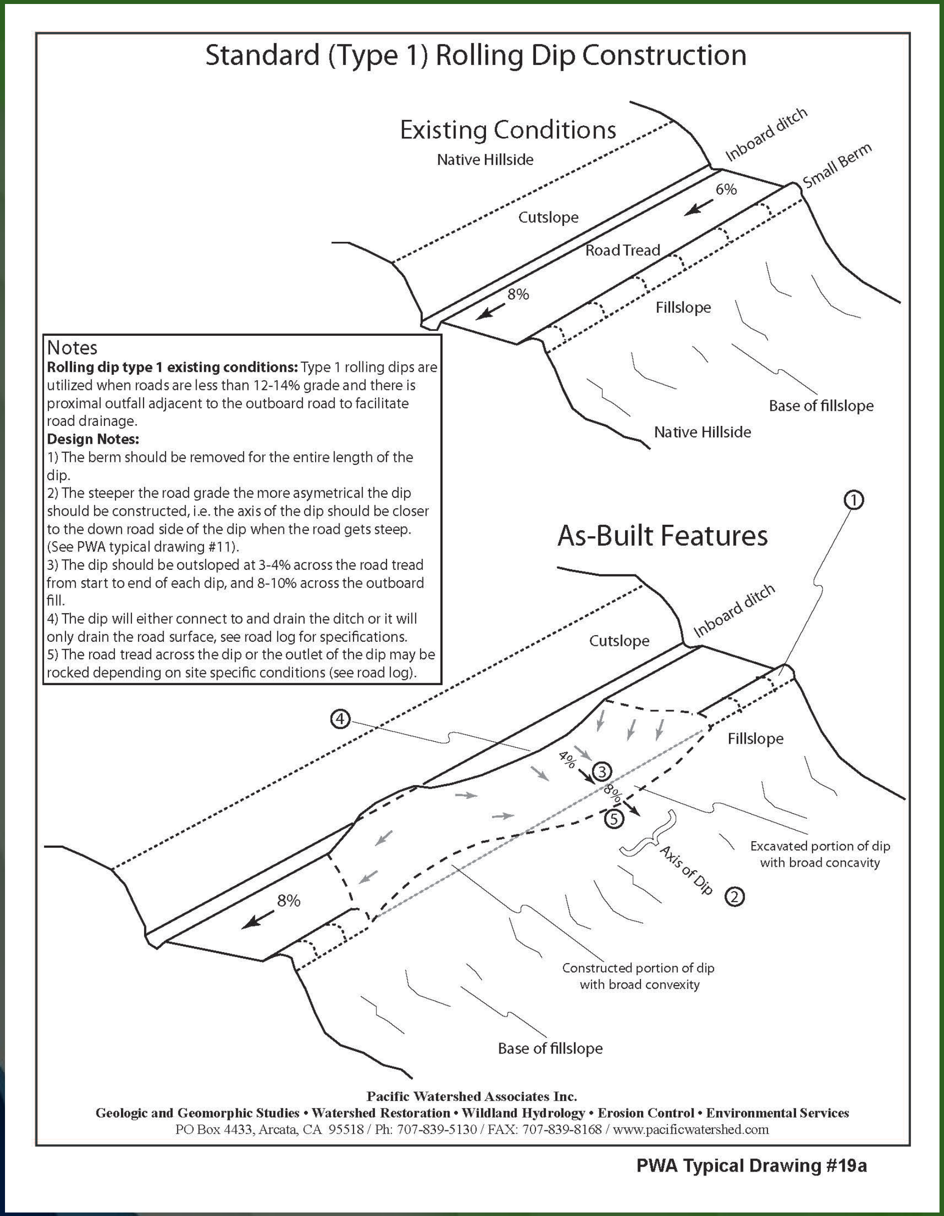
Different types of rolling dips

PWA has developed typical drawings for three different rolling dip types, the different dip types are meant to be employed as necessary based on the existing road and hillside geometry.

Type 1- employed in areas with low to moderate road grades and small outboard berms
Type 2- employed in areas where the road is through-cut or exhibits thick berms on the outboard road
Type 3- employed where the road grades are relatively steep and developing reverse grade on the dip would inhibit vehicle traffic

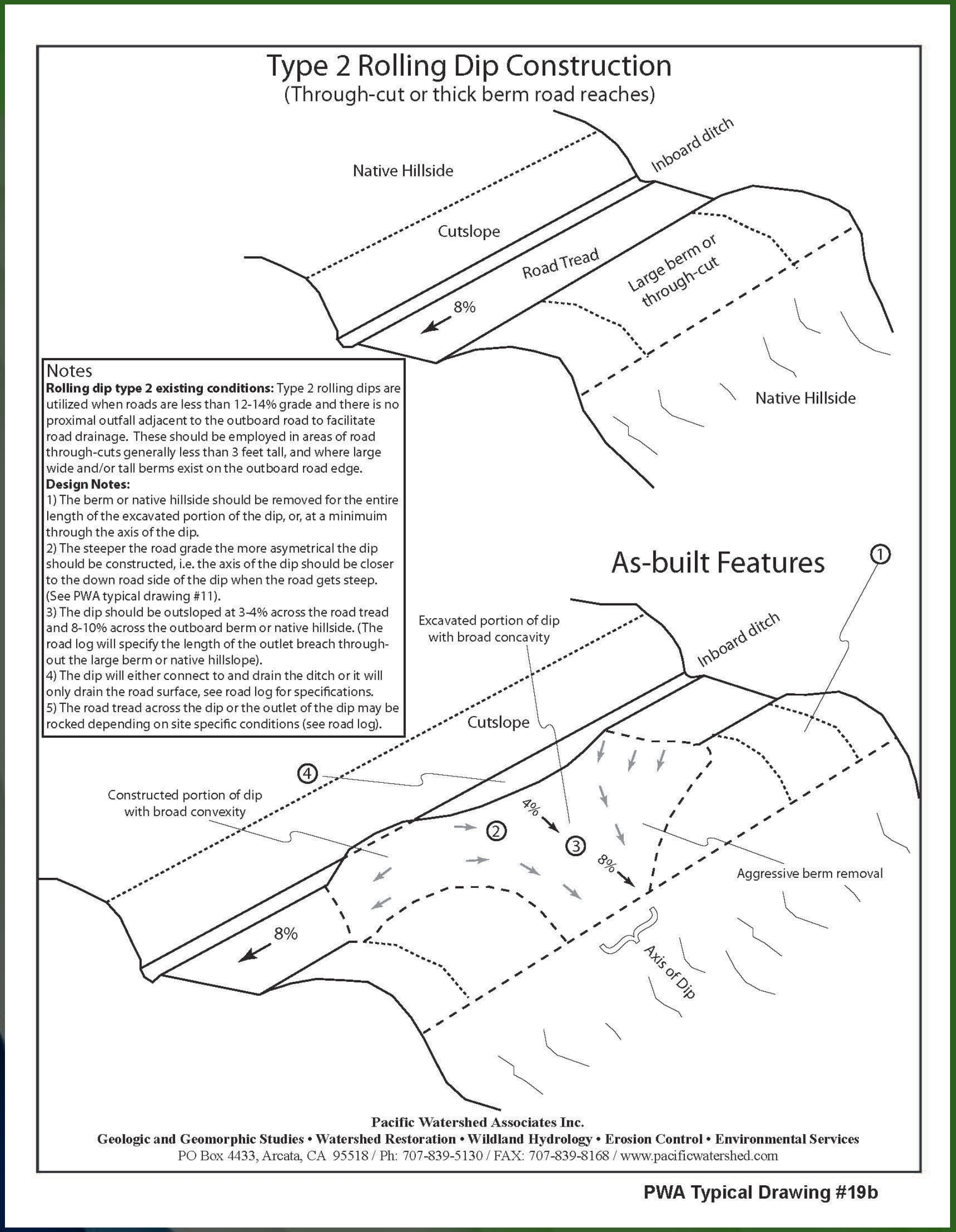
TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ROLLING DIP-TYPE 1



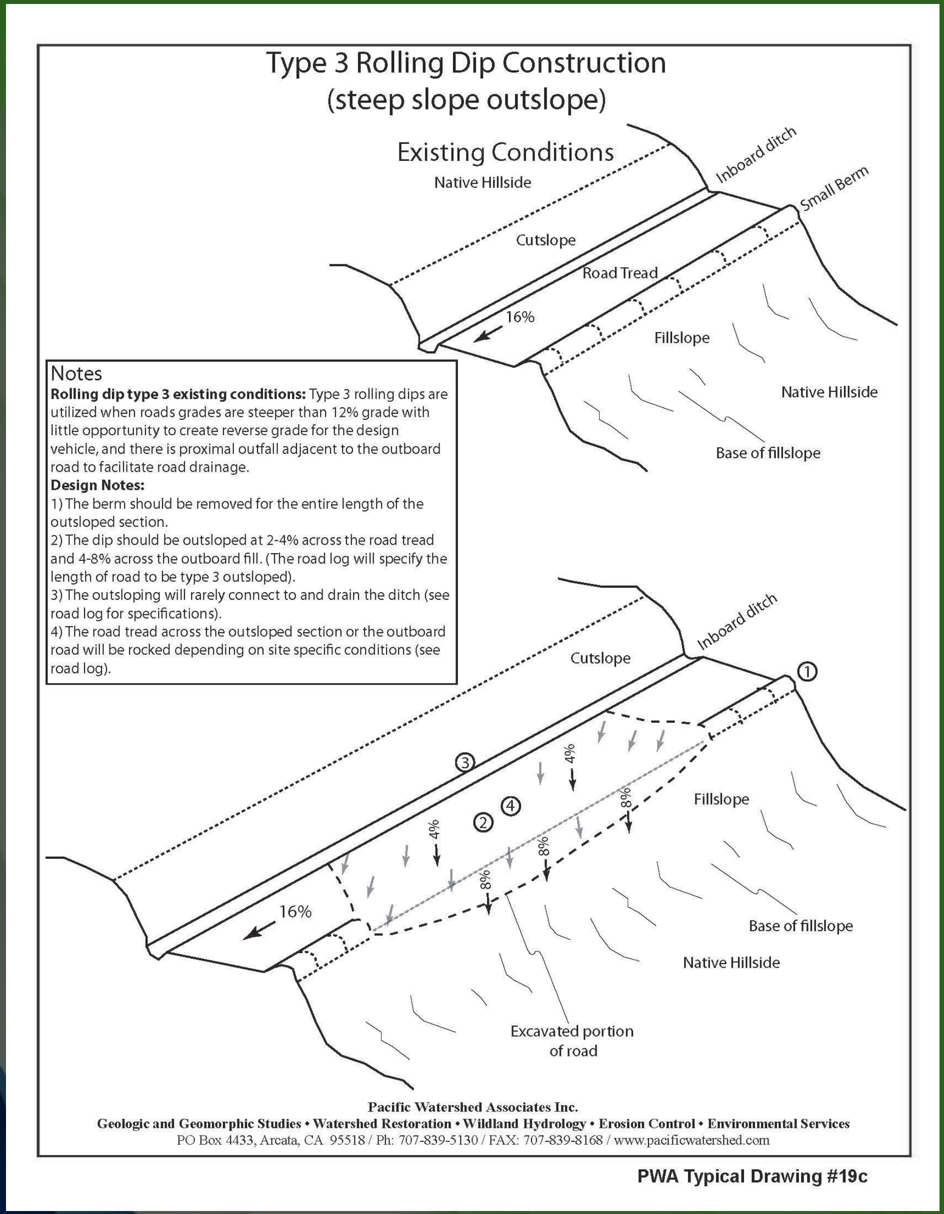
TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ROLLING DIP-TYPE 2



TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ROLLING DIP-TYPE 3



TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Note:

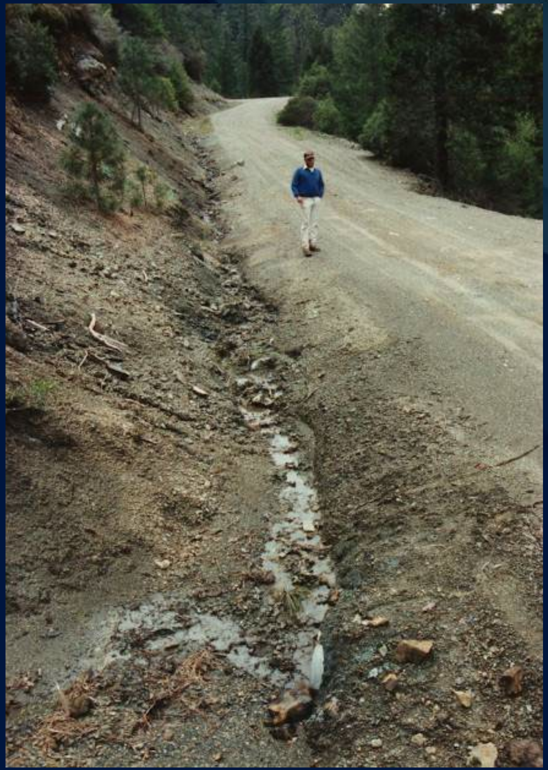
(1) There are several rolling dips on this photo

(2) The final road approach is heavily rocked

(3) The road is generally shaped to conform to the natural hillside

Rolling dips on a stream crossing approach

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY



Insloped road with ditch – hydrologically connected

Outsloped road with rolling dips – ditch retained

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

CHOOSING ROLLING DIP FREQUENCY AND DISCHARGE LOCATIONS NEED TO BE WELL THOUGHT OUT

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ON CONVEX SURFACES TO ENCOURAGE DISPERSAL AND INFILTRATION OF ROAD RUNOFF

ON HIGHLY VEGETATED HILLSIDES

ON LOW GRADIENT HILLSIDES

AS FAR AS PRACTICAL FROM THE STREAM NETWORK (THE CLOSER YOU GET TO A STREAM CROSSING THE MORE FREQUENT YOUR DIPS SHOULD BE)

ON STABLE GEOLOGIC SURFACES (IN OTHER WORDS, NOT ON LANDSLIDES OR HILLSIDES PRONE TO GULLY EROSION)

ON STRAIGHTER SECTIONS OF ROADS (NOT ON OR RIGHT BEFORE A HARD TURN TO THE INSIDE OF THE ROAD)

ON OUTSIDE TURNS IN THE ROAD (LIKE A NASCAR TURN)

ON VEGETATED RIVER TERRACES WHEN THERE IS NO OTHER CHOICE

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

TIPS FOR DETERMINING THE APPROPRIATE FREQUENCY FOR ROLLING DIPS

(1) Dip frequency should decrease as the road approaches a stream crossing…
(2) In general, steeper road grades and roads proximal to streams require more frequent road drainage structures
(3) Dip frequency should be based on the performance of the existing road drainage, not based on prescriptive measures..
(4) Road drainage performance should be monitored through the winter months and adaptively managed by prescribing more frequent dips where appropriate

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Maintain a large riparian buffer of vegetation between grading projects and streams. Steeper and less vegetated hillsides require longer riparian buffer strips to protect water quality.

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

ROADS WHERE STREAMS SHOULD BE:

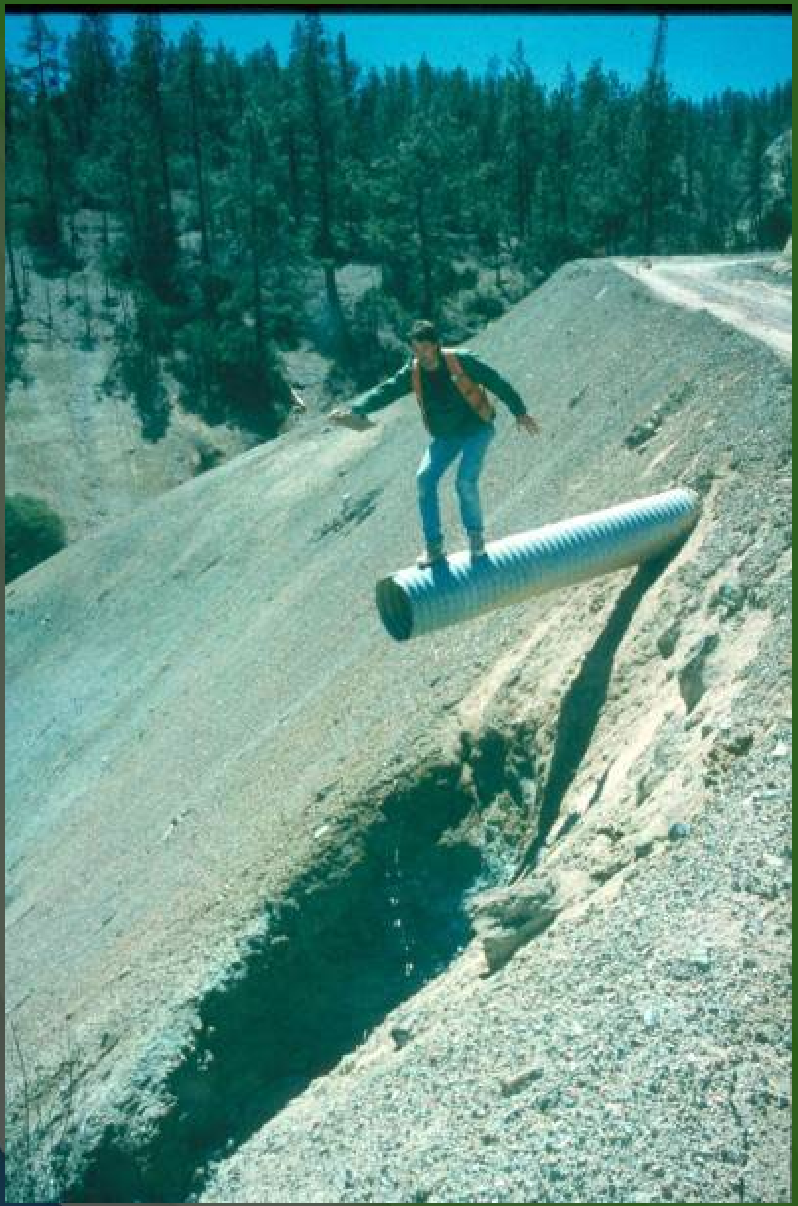
ROAD SURFACE AND STREAM BANK EROSION AND NO RIPARIAN BUFFER

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Roads where streams should be, no riparian buffer

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

DITCH RELIEF CULVERTS



TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

When are inside ditches and ditch relief culverts a good option?

WET HILLSIDE CONDITIONS- IN REALLY WET AREAS OR WHERE THE DITCH IS DRAINING A HILLSIDE SPRING, DRCS ARE A GOOD OPTION…

ON STEEP ROAD GRADES- ON STEEP ROAD SECTIONS WHERE OUTSLOPING OR ROLLING DIPS ARE NOT FEASIBLE, DITCH AND DITCH RELIEF CULVERT CAN BE EMPLOYED…

TO MINIMIZE DISCHARGE ONTO GEOLOGICALLY UNSTABLE AREAS- ITS BEST TO CARRY WATER IN A DITCH RATHER THAN ALLOW IT TO DISCHARGE WHERE EROSION AND OR SEDIMENT DELIVERY COULD OCCUR…

WHERE BERMS ARE REQUIRED TO ASSURE VEHICLES STAY ON THE ROAD…

IN AREAS OF RUN-ON FROM THE HILLSIDE..

ANY LOCATION WHERE YOU DON'T WANT TO DISCHARGE RUN OFF OVER THE FILLSLOPE

ON PAVED ROAD SECTIONS….

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

DRC installation

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Full-round downspout

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Energy dissipation

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Perforated DRC flex pipe spreaders

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

DRC drop inlet

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Some final thoughts

And a little review

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Common issues with treating connectivity…

Not all road segments are hydrologically connected and complete hydrologic disconnection is not possible for most roads (typical levels).

Connectivity has two forms to be treated:

- Hydrologic connectivity – the emergence, collection, rapid routing and discharge of road-related runoff to stream channels (channel stability and drought implications)
- Pollutant connectivity – the generation and transport mechanism for sediment and other pollutants to be delivered to streams, lakes and wetlands (aquatic habitat implications).

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

- DRC spacing must be based on ditch erosion, slope erosion and stream proximity; when "required spacing" (from tables) does not make sense!
- Drainage structure spacing will decrease as you approach a stream or stream crossing; second structure spacing is critical
- Not all filter strips are the same (when 100' ≠ 100')
- OS roads with inside ditches (when to use)
- Rolling dip spacing (should be performance-based):

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

- Identifying the best discharge sites (rather than the table distance; e.g., through cuts, convex slopes, stable rocky slopes, flood plains and terraces, buffer characteristics, etc.). *Think performance!*
- Are energy dissipators always needed? If they are, what does that tell you ? (too much water)
- When a road can't be drained... (through cuts, fall line roads)
- When a road shouldn't be drained (unstable areas, connected gullies, streamside roads

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

- Construct outsloped road shapes with no berms, and periodic rolling dips, disconnecting crossing approaches,
- Utilize inboard ditches only where springs are present along the cutbank, or to collect runoff from upslope,
- Disconnect ditches using frequent ditch drains,
- Minimize ditch grading; revegetate connected ditches
- Avoid through-cut roads & roads down the axis of swales,
- Do not pipe riparian road runoff directly to streams; use perforated flex pipe on contour to disperse flow,
- Culvert spacing should result in no hillslope gullies,
- Dewater connected gullies, even if they are stable, and
- Construct properly designed and sized sediment basins.

TREATMENT STRATAGIES FOR ROAD SURFACE RELATED EROSION AND SEDIMENT DELIVERY

Road connectivity comparison following road storm-proofing along 15.2 miles of forest roads.				
Connectivity site type	1998 Connectivity (pre-treatment) (ft)	Connected road/ditch length of forest roads (ft)		Average connected length as of 2005
		2004	2005	
Stream crossing approach	23,930	14,100	3,630	84 ft
Ditch relief culvert	27,000	9,450	1,600 [1]	178 ft
Gully/rolling dips	3,860	5,325	800 [1]	200 ft
Other	6,350	825	0	0 ft
Total (15.2 mi):	61,140'	29,700'	6,030'	108 ft
Connectivity	**76.2%**	**37.0%**	**7.5%**	--