# 6. Conclusions

Because of the nature of this thesis, many of the conclusions that were drawn have already been discussed in the Results section. The conclusions here will include the relative contribution of past, present, and future sediment within the respective influential subwatersheds. Recommendations are then proposed in order to mitigate sediment generated from sources that are triggered by anthropogenic influences. Finally, this chapter includes the limitations of this research, identifies possibilities for further research, and explains how this work has contributed to the general knowledge of sediment production processes and sources in the San Pedro Creek Watershed.

## 6.1 Changes in sediment sources

Past and present sediment production was most significant in Crespi, North, Middle, South, Sanchez, Shamrock, and unnamed 5 subwatersheds. Most of the total calculated sediment was generated from the Middle and Sanchez subwatersheds. This is largely because of an impervious road constructed along the slide-prone hillslopes of the Sanchez subwatershed (VanderWerf 1994) triggered many slides and subsequent gullying while past farming practices along the lower hillslopes generated the same response in the Middle subwatershed. Past farming and possibly grazing practices have also compacted hillslopes in Crespi, North, Middle, and unnamed 5 subwatersheds. As urban development expanded, new roads that triggered many gullies and subsequent surface erosion were created in Sanchez and Shamrock subwatersheds. Drainage terraces constructed in the North subwatershed to protect residential development from unstable hillslopes provide direct delivery of sediment from surface erosion and in some cases triggered landslides. Past storm events have generated many natural landslides, especially in the Middle, South, and Sanchez subwatersheds, effectively delivering short-term sediment to San Pedro Creek. Pedro Point II and Crespi are small intermittent drainages with only seasonal flow that have still generated a substantial amount of sediment from recreational and farming practices, respectively. These drainages have also delivered significant amounts of short-term sediment to the network during high flow events in the rainy season.

Future sediment production is most likely to be from many of the same subwatersheds including North, Middle, Sanchez, and unnamed 3. Hillslopes partially covered by urban development and paved roads will continue to erode into gullies where runoff from the impervious surface concentrates in the North, Sanchez, and unnamed 3 subwatersheds. The gullies in the Middle subwatershed will continue to incise while draining sediment into the ditch along the valley and into the main channel through culverts in the Middle/South subwatershed. However, some of the upslope runoff may be diverted as existing trails have been decommissioned along the ridgeline of the Middle subwatershed. Lack of use on these trails will promote new vegetation growth somewhat decreasing the amount of runoff contributed to the gullies. Future intense rainfall events will likely continue to trigger natural landslides especially in the South, Middle, and Sanchez subwatersheds guaranteeing sources of short-term sediment supply.

6.2 Proposed recommendations for sediment mitigation

Sediment was generated from both natural and anthropogenic sources. Little can be done to reduce sediment production from natural sources besides implementing large, labor intensive, and often impractical and expensive engineering structures. Some of these structures would include the terraced hillslopes that already exist on many slopes in the North subwatershed, concrete revetments, retention walls, and large culverts such as that draining Highway 1. Instead of stopping excessive sedimentation, these structures often merely displace the sources elsewhere. Additionally, such massive techniques are generally implemented where anthropogenic influence has already created a problem, often just exacerbating the issue as is exhibited on the hillslope terraces of the North subwatershed. Hillslopes in the upper South subwatershed have been and remain in fairly natural condition, minimizing the need to implement large-scale sediment reduction structures, as most sediment generated from this subwatershed is short-term.

Bioengineering techniques provide a simpler, pragmatic, inexpensive, and more environmentally friendly solution. Some of these methods have already been utilized in San Pedro Creek where a new bridge was constructed along the Middle Fork. One such method that is particularly applicable to the hillslopes is vegetation planting. Willows were planted to stabilize channel banks and reduce the effectiveness of surface erosion while simultaneously creating steelhead habitat and eventually contributing to water temperature regulation. Areas with little vegetation or barren soils could benefit from vegetation stabilizing hillslopes and providing a riparian buffer through which upslope sediment would be filtered. Previous restoration efforts in Pedro Point II subwatershed have already incorporated revegetation and other simple techniques including mesh retention over barren soils, water bars along trails to diffuse runoff (Figure 101), cut tree and shrub branches that provide stabilize and nutrients for new vegetation (Figure 102), and supply gravel on the roads still occasionally used to promote soil aeration for better infiltration of runoff (Figure 103). These techniques appear to be effective on the hillslopes in Pedro Point II subwatershed that have become nearly impervious from the former off- road motorcycle use. Some of these practices could also be implemented along the lower northern slopes of the Middle subwatershed where previous farming practices created nearly impervious lands and current gullies that extend to the base of the slope. Marsh (1998) identifies additional site-specific mitigation materials and techniques that are generally used for stream bank stabilization but may be applicable for some of the erosion along the lower hillslopes include straw bales, fiber nets (burlap), and constructing sedimentation basins.

Some of the simpler engineering structures already in place that have proven to be ineffective could be modified or removed. Tarps draped across problem areas to abate surface erosion prevent both evaporation of saturated soils and establishment of vegetation. In a few areas, these tarps have washed downslope and are now preventing new vegetation from growing where they have been displaced (Figures 104 & 105). The partially paved Coastside Boulevard (Figure 106) that was built in 1915 (VanderWerf 1994) concentrates runoff to a few sites on the lower slopes creating gullies. Erosion in one gully is so severe that sandbags, tarps, retention poles, and a failing culvert have been installed to stabilize the trail and try to reduce further erosion (Figure 104). While delaying erosion, these props are proving to be ineffective in impeding long-term erosion. Removal of the pavement along the trail, aeration of the underlying soils, and installation of many more water bars would effectively diffuse runoff and reduce the erosion at this concentrated site. To effectively mitigate sediment generated from this gully and prevent further incision, large-scale modifications would likely need to be made to the gully due to the already extensive depth. General incision along many of the trails throughout the subwatershed is severe enough in places that grading followed by the installation of new water bars may be necessary.

Figure 101: Existing and apparently effective sediment control measures implemented in Pedro Point II subwatershed.

Figure 102: Tree and shrub cuttings (at arrow) placed along trail in an area with deep incision to reduce erosion and promote vegetation growth.

Figure 103: Large gravels spread onto the nearly impervious surface of the road. Over time the gravels will aerate the soils making the road more permeable to moisture.

Figure 104: Ineffective erosion control structures. Tarps have washed downslope over the sandbags supporting the trail in just one rainy season.

Figure 105: Tarps proving to be ineffective control measures have washed downslope of an area of an eroding area along the Coastside Boulevard.

Figure 106: The partially paved surface of the Coastside Boulevard.

## 6.3 Limitations

Throughout the course of this research multiple limitations regarding the accuracy of the data were recognized. These following limitations affect the application of the data to mitigate sediment:

- Smaller landslides may not have been observed when occurring between years of aerial photographs. Colluvium was discovered along upper trail cuts in several locations where no evidence of upslope landslides was found on the aerial photographs (Figure 107).

- The scale of the 1941 aerial photographs reviewed for landslides was relatively small at 1:24K. At this scale many smaller landslides were not visible.

- Thick vegetation on the hillslopes obscured many small landslides. A study conducted in a forested landscape of southwestern British Columbia found obscured landslides to make up to 85% of the total failures comprising 30% of the total mobilized debris (Brardinoni *et al.* 2002). SPCW is not heavily vegetated throughout and these values are likely too high for this landscape. However, the still significant lack of visibility may partially account for the relatively small number of slides found in the South subwatershed relative to others less vegetated. It is also possible that fewer slides were obvious because of the hillslope stability provided by the roots of the vegetation.

- Landslides were difficult to accurately digitize from the aerial photographs onto the georeferenced coordinate system. Most of the photographs had significant distortion that was adjusted while digitizing each individual landslide. The landslides were traced as precisely as possible, but there is likely an overall error in accuracy somewhat compromising the results.

- The quantitative values used are crude and represent the minimum levels of sediment entrained since 1941. Overall values for surface erosion could not be made throughout the entire watershed and many landslides, and possibly gullies, were not visible on the aerial photographs and consequently, not included in the total. However, comparisons of relative sediment contributions were identified and isolated to the distinct subwatersheds.

- Anthropogenic sources were assessed more fully than natural sources. The thick vegetation makes SPCW inaccessible by foot and difficult to visualize on aerial photographs limiting access to natural sediment sources. However, anthropogenic sources are more accessible and often more influential than natural sources in supplying long-term sediment. Since sediment mitigation efforts are most likely to be applied to anthropogenic sources, the overall objective of this study was still met.

Figure 107: Unconsolidated landslide material along the upper hillslope of the Valley View Trail in the Middle subwatershed. Landslides were not observed on aerial photographs but evidence of occurrence was found in the field.

## 6.4 Possibilities for future research

In order for a sediment source analysis of SPCW to be complete, a channel bank assessment is needed. While the hillslopes have proven to contribute a substantial amount of sediment to the stream network, the channels deliver sediment with the best connectivity at possibly more significant levels.

If possible more detailed fieldwork identifying landslides that were not obvious on the aerial photographs would support and contribute to the overall values obtained. Since the vegetation in SPCW is so dense, most of the data were extracted from digital GIS data, past aerial photographs, and fieldwork along trails and roads, which was biased toward anthropogenic sources. More extensive surveys on private lands that have a moderate level of accessibility (Picardo, Shamrock, and Crespi Ranches) would add data and improve the accuracy of the hillslope sediment source analysis. Landslides along channel terraces that are obscured by thick vegetation would be obvious during fieldwork through a thorough channel assessment.

To achieve accurate quantitative values of surface erosion, a long-term monitoring study would need to be conducted. Either erosion pins or sediment traps could be used to measure the annual downslope movement of soil. Turbidity meters installed in tributaries would measure the delivery of sediment to the stream network. Figures 72a-b in Section 5.2.5 represent the significance of surface erosion over just one wet season and the possible contribution that was unable to be fully assessed from this study.

## 6.5 Contributions of the study

This study identified past, present, and likely future natural and anthropogenic sources delivering sediment to San Pedro Creek. It spatially traced changes in sediment production over time simultaneously with associated contributing natural and anthropogenic factors. Based on this research, sediment mitigation efforts aimed at enhancing steelhead trout habitat and ensuring the protection of the population can be effectively implemented. The reduction of sediment in the stream network also increases the water quality enhancing the overall value of the ecosystem. This study provides a comprehensive set of baseline data upon which future long-term sediment-related research in SPCW can be developed. Finally, as a result of this study, extensive literature was gathered, new GIS data were generated, and field data and photographs were collected and analyzed expanding the knowledge base of sediment production and sources in SPCW.