LOWER VINEYARD CREEK
FLOOD CONVEYANCE ASSESSMENT
NOVATO, CALIFORNIA

Prepared For:

County of Marin, Department of Public Works,
Flood Control and Water Conservation District

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1.0 INTRODUCTION

This report summarizes the results of a hydraulic modeling study completed by Kamman Hydrology & Engineering, Inc. (KHE) of San Rafael, California to identify opportunities to increase and maintain flood conveyance in lower Vineyard Creek. The reach of interest is located in Novato, California between Arbor Circle and McClay Road (see Figure 1). Following flooding of adjacent residences during the December 31 2005 storm event, the County undertook emergency measures to clear the reach, and initiated a systematic assessment of measures to prevent future flooding events. This reach supports steelhead; therefore, efforts are also being directed toward promoting and maintaining in-stream habitat.

A prior letter report, prepared by KHE for Marin County DPW and presented in Appendix B, provides: a summary of the site setting; background on the current conditions; and, a description of the impacts of the December 31 flood impacts. The letter identifies opportunities for changes in creek management to improve flood conveyance and in-stream habitat. This channel hydraulics assessment represents the next phase of work. This study evaluates hydraulic conveyance of the current channel configuration, and identifies additional measures to improve and maintain conveyance. A Separate assessment (White and Prescott, 2006) evaluates opportunities for flood reduction via flow redirection.

This work was completed on behalf of The County of Marin Department of Public Works (DPW), Flood Control and Water Conservation District (Flood Control) under Contract Number 06-322.

2.0 OBJECTIVES:

The objectives of this study are to:

2.1. Evaluate the current flood hazards within the study reach and assess the need for additional flood-hazard mitigation measures;

2.2. Evaluate the efficacy of a suite of additional flood reduction options identified by the County;

2.3. Determine the combination of additional measures that most effectively minimize future flood risks and maintenance requirements while promoting a healthy creek and riparian corridor; and,

2.4. Identify locations where bank erosion risks are high and recommend erosion protection measures.

This document describes the modeling approach used to conduct this study, summarizes model results, and recommends next steps for management of this Vineyard Creek reach.

3.0 CONCLUSIONS

3.1 The channel geometry established by the County during the spring 2006 (post-flood) provides adequate conveyance for the 50-year flood at most locations.

3.2 Upstream of the Center Road culvert (Reach A, Figure 1), the hydraulic model predicts localized over-bank flooding at and above the 50-year flows. At these locations bank elevations should be raised 1-2 feet locally to protect the adjacent homes.

3.3 The Center Road culvert acts as a constriction, and is overtopped during the largest storm events. Modeling indicates that a 50% increase in flow area (8-foot increase in width), or conversion to a free-span bridge is required to pass peak flows associated with a 50-year flood event.

3.4 Downstream of the Center Road culvert, (Reach B, Figure 1), the channel geometry established by the County as part of post-flood emergency measures is adequate to convey both the 50-year and 100-year flood flows. Because Reach B, as modified by the County, is able to convey both the 50-year and 100-year flows without overtopping its banks, no additional modifications to Reach B are recommended (See Section 6.1).

KHE considered the following suite of options prior to reaching this conclusion (See Section 7.2):

i. **Lowering the Wilmac Avenue wall:**

The maximum predicted water surface elevations for Q50 and Q100 storms under existing and future conditions (Figure 8c) extend to within 1.5-2 feet of the top of the Wilmac Avenue wall. On the opposite bank, water levels reach to within 0.25-feet of the top of bank. Because the wall and banks are not overtopped (Figure 17), a reduction is wall height will not reduce flood hazards within the reach.

When overtopping flows occur[1], model results indicate lowering the Wilmac Avenue wall will reduce maximum water surface elevations by up to 0.2 ft between cross-sections B3 (above the utility crossing) and A8 (just upstream of Center Road). The remainder of the reach is unaffected.

ii. **Expanding the overbank channel and setting back the Wilmac Avenue wall;**

Hydraulic modeling results predict that a 12-foot floodplain expansion produces only a sight (0.25 ft) reduction in peak water surface elevations at the cross section with the least freeboard (B-6) [Figure 17]. The minimal flood risk reduction provided does not warrant implementation.

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[1] Flows overtopping the channel banks are only predicted assuming extremely overgrown conditions.

iii. **Expanding the Low-Flow Channel:** Sediment transport through the reach is high during both intermediate and large storm events. The existing cross-section is likely larger than what will be supported by the anticipated flow and sediment inputs. As such, further expansion of the low flow channel is not recommended. Incoming sediment will rapidly fill the over-excavated channel yielding little long-term benefit for the project.

iv. **Berm Construction:** The hydraulic model of existing and future conditions predicts Q50 and Q100 peak water levels will not flood McKeon Court homes (Figures 13 & 15). KHE did not evaluate berm construction with the model because changes to the topography associated with berm construction are above the predicted maximum water surface elevation. As such, simulating berm construction would not alter model results.

Most residences along McKeon court maintain positive drainage across the parcels from the street to the creek. This drainage pathway functions effectively during all but the extreme storm events. During extreme events, a berm prevents creek driven flooding, but also precludes drainage of direct precipitation. Berm construction, if undertaken, will require additional design and construction of an active or passive drainage system for homes located behind the berm.

3.5 To maintain flow conveyance and provide adequate flood protection periodic channel maintenance will be required below the predicted 2-year flood (Q2) water level. Maintenance will entail excavation of sediment, vegetation and debris within the channel banks. Repair and protection of eroded banks may also be required below the Rena Court turn.

3.6 Establishing a healthy riparian corridor (understory and canopy) through bank re-vegetation (above the Q2) will not significantly alter flood conveyance through the reach. Shading provided by a mature canopy will reduce in-channel vegetation growth, and lower creek water temperatures.

3.7 The invert elevation of the Center Road culvert acts as a grade control for the upstream and downstream reaches. To avoid destabilizing the bed and banks of these reaches, and maintain sediment transport capacity, the culvert invert elevations should not be modified.

3.8 The utility crossing (Cross-section B6) creates a hydraulic step in the bed and acts as a grade control structure in the reach. The strong role of this grade control feature may be a product of the downstream widening of the channel at the Rena Ct turn. Again, removal of the feature is not recommended to protect the stability of the bed and banks.

3.9 Through Reach C (downstream of Rena Ct.), the channel narrows (cross-sections C3-C6) producing higher flow velocities and locally increasing the bank erosion potential. (Bed erosion is limited by a tight clay substrate). Within the cross-section, there is adequate room to lay back the incised banks. Widening the channel through Reach C will locally reduce maximum water levels, and reduce bank erosion and debris jam risks.

3.10 Through Reach C, the opportunity exists to reduce bank slopes and widen the corridor. Although not necessary for flood conveyance, widening and/or terracing Reach C cross-sections would enhance the riparian corridor.

3.11 The McClay Road culvert easily passes the Q50 and Q100 peak flows. No modifications to the culvert are needed for flood conveyance purposes. However, the County identified the steep slope and vertical drop at the downstream end of the culvert as an impediment to fish passage.

4.0 RECOMMENDATIONS

4.1 Construction

4.1.1 Reach A: Improve (elevate 1-2 feet) banks at cross sections A4 and A5 to prevent localized over-bank flooding.

4.1.2 Reach A: Improve Center Road flood conveyance by increasing flow area to pass the 50-year flood. Do not alter invert elevation. An increase in flow area can best be accomplished by constructing a free span bridge. A bridge minimizes restrictions to flow and sediment conveyance. If this is not feasible, expanding the culvert to its maximum available width (estimated to be 21 ft) is advised

4.1.3 Reach C: Lay back the banks in channel cross sections C3-C6 to reduce local flow velocities, and decrease the potential for debris jams and associated backwater effects during storm events.

4.1.4 Evaluate and establish positive drainage between adjacent storm drains and channel. This includes roads and parking lots. Insure outfalls and associated bank protection is adequate to maintain bank stability.

4.2 Maintenance

4.2.1 Below the Q2 water surface, maintain existing channel geometry through periodic maintenance consisting of clearing sediment and debris. Annual maintenance inspections of the corridor will be required to determine if accumulated sediments/vegetation/debris are likely to reduce conveyance. Debris jams, and large or excessively course sediments loads should be removed immediately.

4.2.2 Monitoring of creek sediment dynamics is needed to establish maintenance criteria under typical (non-extreme) sediment loading conditions. (See Section 4.4) Initially, a 25% reduction in the Q2 flow area can be used as a trigger for channel maintenance. Refinement of maintenance criteria should be undertaken once channel and sediment dynamics are better established through monitoring.

4.2.3 Above the Q2 water surface, maintain a healthy riparian corridor through annual removal of invasive, densely growing vegetation, snags and foreign objects.

4.2.4 Regularly inspect critical conveyance sections and stabilized banks at the Center Road crossing, and at cross-sections C3-C6.

4.3 Corridor Management

4.3.1 Above the Q2, undertake selective riparian vegetation placement and management to promote and protect a healthy stream bank ecosystem.

4.3.2 General: Resource managers should be aware that the bank and bed stability through the reach are constrained by present base level controls. Modification of these features will affect adjacent bed and bank stability.

4.3.3 Riparian Vegetation: Hydraulic analysis indicates a natural stand of riparian vegetation, including canopy and understory, does not impede flood conveyance. Bank vegetation management will be required to maintain a natural vegetation density (e.g. limiting invasive exotics) which will be beneficial for both flood protection and riparian habitat. A relatively clear understory and a well-established canopy of trees will best benefit the corridor by reducing in-stream vegetation growth and improving water quality.

4.3.4 The County identified the McClay Road culvert as an impediment to fish passage. Lowering the incised upstream reach is not recommended because it will further exacerbate channel incision and bank failure in Reach C. Remedies for reducing the bed drop will require creating step-pools downstream that gradually raise the bed to the elevation of the McClay Road culvert.[2] Alternatively, a "Rock Ramp Fish Pass" could be constructed to provide access.

4.4 Monitoring

Establish photo points, install water level gages and conduct annual cross-sectional surveys just below and above the Center Road culvert, and above the McClay Road culverts to monitor water levels and transient sediment loads through the reach. This information will serve as the baseline for Center Road culvert design, and establishing long-term maintenance needs for both the channel and banks.

To monitor sediment dynamics within the reach, baseline and annual surveys (a longitudinal profile and cross-sections at key locations [the Center Road crossing, the middle of Reach B, and in the Reach C narrows]) will be required to establish controls. Sediment samples should be collected and analyzed to determine the sediment grain-size distribution through the reach. Once established, this information and the anticipated range of flow rates can be used to determine the channel geometry and slope necessary to maintain sediment transport through the reach. This information will serve as the basis for establishing channel maintenance criteria.

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[2] Additional information required to design these features includes monitoring of downstream water levels and peak flow velocities, assessment of bed characteristics, and a comprehensive survey of the downstream channel and bank topography.

5 STUDY APPROACH:

To address the study objectives, KHE developed a hydraulic model of Vineyard Creek that predicts annual and storm driven water surface elevations and flow velocities in the stream reach between Arbor Circle and McClay Road. The "Existing Conditions" (EC) model configuration, reflecting current (post-emergency measures) channel conditions is the baseline for the assessment. KHE compares the anticipated EC water levels and flow velocities with a "Future Conditions" (FC) scenario, to evaluate the effects of re-vegetation and maintenance efforts. KHE also assessed potential flood hazard, bank erosion and channel maintenance benefits associated with a range of proposed channel modifications and levee setback scenarios throughout the reach. We simulated each proposed mitigation measure individually to determine the potential flood reductions. Based on these results KHE formulated a "Recommended Measures" (RM) scenario that maximizes the efficacy of the flood reduction benefits throughout the reach.

This comparative hydraulic modeling analysis addresses the following:

1. <u>Hydraulic Conditions</u>: A description of predicted flow conditions throughout the reach identifying the estimated maximum water surface elevations associated with the 2-, 5-, 10-, 50 and 100-year floods. Significant changes in flow structure and its relationship to the creek corridor are presented.
2. <u>Bank and Bed Erosion Potential:</u> An evaluation of erosion potential based on predicted flow velocities, stream power, bank steepness and proximity to in-stream structures.
3. <u>Culvert Flow Conveyance:</u> An evaluation of the impacts on flooding and flow structure associated with the McClay Road and Center Road culverts.
4. <u>Vegetation Impact Assessment:</u> Evaluation of the impacts of re-vegetation, (represented as increases in bank roughness) on maximum water surface elevations and flow structure.

5.1: <u>Hydraulic Model Configuration</u>

KHE prepared a HEC-RAS, one-dimensional, depth integrated steady flow model of Vineyard Creek. The model encompasses approximately 2500 feet of Vineyard Creek from the upstream boundary at Arbor Circle to the downstream boundary at McClay Road. (Figure 1). Two concrete box culvert road-crossings (at Center Road and McClay Road) are within the model domain. The remainder of the reach is open earthen channel. The channel cross-sections, (locations are illustrated on Figure 1), extend to the limit of flooding observed during the January 2006 storm event. Topographic surveys conducted by and for Marin County in April 2006 serve as the basis for the modeled cross-section geometry. The data set includes total station surveys within the channel corridor that extends into Wilmac Avenue. Site located level lines extend the cross sections through parcels to the centerline of McKeon Court[3]. The system is broken into four consecutive reaches, labeled A through D on Figure 1, with inflow points at the upstream boundary (Arbor Circle) and at the ninety (90) degree bend in the channel at Rena Court.

5.2. Design Flow Estimates

To evaluate the hydraulic performance of the system, KHE simulated the range of anticipated flow rates through the reach. Table 1 summarizes the assumed inflow magnitudes associated with the 2-, 5-, 10-, 50-, 100-year return periods.

TABLE 1: VINEYARD CREEK PREDICTED INFLOWS AND RETURN PERIODS

Return Period (yrs)	Upstream Inflow Arbor Circle (cfs)	Lateral Inflow (Rena Court) (cfs)
2	183	44
5	244	59
10	482	125
50	718	197
100	831	229

KHE estimated the 2-year and 5-year peak flows based on Caltrans/USGS regional flood frequency equations (USGS, 1977), as a function of drainage area, mean annual precipitation and altitude. Drainage areas for Vineyard Creek and the Rena Court inflows are estimated at 1.69 ac (Collins, 1998) and 0.34 ac (L. Lewis, Marin DPW, 2006, personal com.), respectively. The 10-year, 50-year and 100-years inflows are based on a derived correlation between unit drainage area and FEMA flow estimates in local area creeks (KHE Inc., 2003).

5.3. Bed and Bank Roughness:

The Manning's coefficient (n) is used to define the bed and bank roughness in the channel and over-bank areas. Model parameters define existing and future in-channel and bank roughness coefficients (Table 2) using standard values for earthen beds, and banks with light [Existing Conditions (EC)] and dense [Future Conditions (FC)] vegetation growth. Light vegetation (EC) assumes an earthen excavated channel with no vegetation, and banks with short grass and weeds. The dense vegetation (FC) scenario assumes a clean straight channel with minimal vegetation, and banks covered with light brush and trees. To evaluate system sensitivity to the potential range of roughness values, KHE evaluated an overgrown conditions (OC) scenario reflective of an un-maintained channel. OC roughness assumes the channel has dense weeds as high as the flow depth, and banks covered with heavy stands of brush and trees.

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[3] The County provided all the survey data utilized in this study. The accuracy of KHE's study is subject to the limits of the accuracy of the data provided. Additional field surveys may be needed prior to preparation of project designs.

Model results comparing light (EC) and dense (FC) channel and bank vegetation define the impacts of anticipated planting for bank stabilization and riparian habitat value through the reach. Additional modifications to the reach were evaluated assuming dense (FC) vegetation conditions provide a conservative estimate of long-term conditions through the reach. The proposed modifications are also presented assuming Future Conditions (FC) roughness values (Table 2).

Table 2: MANNING'S ROUGHNESS VALUES (n)

	Bed Roughness (n)	Bank Roughness (n)
Existing Conditions	0.025	0.035
Future Conditions	0.030	0.050
Overgrown Conditions	0.080	0.100

In the comparison between existing and future conditions, we assume bank roughness increases above the Q2 water surface elevation to reflect bank and under story growth. Below the Q2 (water-surface) elevation roughness is assumed relatively consistent through regular creek/floodway maintenance.[4] [5] Below Q2, passive bank re-vegetation will occur between required maintenance activities. Beyond the levee tops, overbank areas are assumed unchanged. This represents no change of conditions in the community outside the Vineyard Creek right of way.

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[4] This maintenance will be required to provide necessary flood conveyance.

[5] County to define.

6. EXISTING CONDITIONS ANALYSIS:

The baseline for this assessment is the “post-emergency measure” channel configuration of the creek corridor (circa spring of 2006). Existing conditions channel cross-sections illustrating the 2-yr, 10-yr and 50-yr and 100-yr water surface elevations are presented in Figure 2. Figure 3 presents the longitudinal profile of the predicted water surface elevations through the reach for these flood flows. Also provided on the figure are the top of bank and top of levee elevations. As noted previously, these elevations reflect the Q2 water surface elevation and the elevation believed to trigger flooding within the corridor.

6.1. Water Surface Profiles and Predicted Flooding

Simulation results presented in Figures 2 & 3 show that current channel capacity is sufficient to pass peak flows up to a 10-yr event. At flows associated with the 50-yr and 100-yr events (Figure 3), flooding is predicted in Reach A approximately 300 ft upstream (cross-sections A4 and A5) and at the Center Road culvert. Between the culvert and the upstream sections, simulated water levels come to within a foot of the top of bank condition in sections A6 and A8. Model simulations indicate the Center Road culvert is acting to limit conveyance during high flow events as discussed below.

In Reach B, between Center Road and the Rena Court turn the predicted Q10 water surface elevations stay within the channel banks. At Q50 flows, the water surface reaches the toe of the Wilmac Avenue wall (Cross-sections B2- B5). Q100 flows rise up to 0.5 ft above the base elevation of the wall. Cross section B4 (RS- 3772) appears at the greatest flood risks where the 50-yr and 100-yr predicated water surface elevations are within 1ft and 0.6ft of the levee top elevation (Figure 2b). The narrow margin of freeboard at this and adjacent locations indicates additional channel capacity may improve flood protection through this segment of Reach B. The newly expanded cross-section through the Rena Court turn provides adequate conveyance, with 2-3 feet of freeboard between the 50-yr and 100-yr peak flow water levels and the designated top of bank. Downstream, in Reaches C and D, the maximum predicted water surface elevations remain 3-6 feet below the designated top of bank, indicating the measures implemented provide adequate capacity to pass the anticipated peak flows. (Figures 2c/d and 3).

6.2. Velocity Estimates, Stream Power and Bank Erosion Potential

Profiles of predicted peak flow velocities for simulated flood events are presented in Figure 4. The relatively steep project reach flows at maximum velocities of 8-15 ft/sec, making it an effective transport reach for sediment. This is confirmed by visual observation and prior geomorphic assessment (Collins, 1998). The high flow velocities predicted at the Center Road culvert are a product of the full flowing narrowed section, and are indicative of the culvert functioning as a flow constriction. The highest simulated velocities occur at the Rena Court turn, another know high-energy location in the corridor. Coherent bank protection measures, placed and maintained by the County, currently protect the bank through this sharp bend.

Downstream, Reach C narrows through, cross-sections C4-C6 resulting in higher channel velocities in the smaller conveyance cross-section. The narrower section of Reach C occurs in a location of locally increased slope where a hardened sand/mud sill limits bed and bank incision. This local velocity spike indicates increased bank scour risk that can be lessened by laying-back the stream banks or placement of erosion protection measures.[6] Maintaining conveyance through this relatively narrow section is important because the deeply incised channel provides no alternate route for flood-wave passage. Further downstream of this narrowed reach, the creek widens slightly and the slope decreases. Peak velocities downstream do not exceed 6 ft/sec yielding a lower risk of bank erosion.[7]

Figure 5 presents the longitudinal variation in Stream Power[8] through the reach as an alternative measure of Vineyard Creek's capacity to erode its bed and banks. The high-energy zones at the Center Road culvert, the Rena Court bend and in the Reach C Narrows identify areas where stream channel and bank erosion potential are highest. Local increases in bed slope are largely responsible for the velocity and stream power peaks. Base level controls in the reach, responsible for these channel steps, are discussed in Section 6.5.

6.3. Culvert Impacts

The predicted water surface elevations and velocity structure indicate that the McClay Road culvert poses little impact to flood conveyance. However, the Center Road culvert appears undersized and unable to convey 50-year and 100-year flood flows. The actual dimensions of the culvert are likely overestimated in the base case analysis because two to three feet of sediment were reported removed from the culvert floor following the December 2005 storm event. To evaluate the impacts of sediment accumulation on the Center Road culvert, KHE performed an additional model runs assuming the bottom two feet of the culvert are blocked by accumulated sediment.

The changes in predicted peak water surface elevations and velocity indicate that 2 feet of sediment blockage in the bottom of the Center Road culvert increases flooding upstream of the Culvert (Reach A) during the 50-yr and 100-yr storm events, and produces overbank flooding in the 10-year storm event. Figure 6 presents the changes in the predicted water surface profile for the 50-year flood flows. Figure 7 illustrates the

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[6] Potential "soft" measures include willow fencing and, placement of erosion mats prior to planting.

[7] Bank stability can be maintained as before through re-vegetation. A decrease in plant density is expected with the establishment and care of native riparian plants. To reduce bank failure risk, where possible bank slopes should be reduced to 2:1 or less. Appendix A presents the proposed changes in Reach C cross-sections.

[8] Stream power is an estimator of the stream's capacity to do work on its surroundings. It is estimated as the product of channel slope and discharge.

increases in water surface elevation Cross-Section A7, where the observed effects are most dramatic. Comparable results were found for 10-year and 100-year flood flows. The model predicts no significant changes in the water surface profile downstream of the Center Road culvert. Water over-topping the culvert will flow down both Wilmac Avenue and McKeon Court potentially creating residential flooding in the area. This illustrates the likely impact of culvert sedimentation or clogging during the December 2005 flood event.

6.4 Flow Constrictions

There are two flow constrictions that likely influence hydraulic conveyance in the project reach. The Center Road culvert limits conveyance and increases the potential for flooding upstream of the structure, due to backwater effects, and downstream through overbank sheet flow via roadways and driveways. The Reach C "Narrows" also provide a reduced cross-section. While the banks at this location are incised sufficiently to preclude overtopping, locally increased flow velocities heighten bank erosion risks through this section. As with the culvert cross-section, blockage at this downstream constriction would likely induce significant upstream flooding.[9] It is important to maximize flow at these locations to maintain conveyance through this Vineyard Creek reach. Proposed measures designed to enhance conveyance at these locations are described below in Section VI: Evaluation of Channel Modification Opportunities.

6.5. Base Level Controls

Throughout the Vineyard Creek project reach, a variety of structures control the bottom elevation (thalweg) of the creek. Both the Center Avenue and McClay Road culverts have concrete bottoms. A utility crossing elevates the bed in Cross-section B6, and a mud sill stabilizes the bed in the Reach C narrows. The result is a relatively steeply sloped project reach (average slope= 0.005) with a sequence of channel bed "steps" where relatively little sediment collects, and glides where actively moving sands and gravels accumulate. These bed features control local channel incision rates. Modification to these "steps" is not recommended at this time. Future consideration of modifications to these bed elevation controls should recognize the associated slope adjustment.[10] Table 3 summarizes bed elevations and channel slopes measured in the reach.

It is interesting to note that the model predicts supercritical flow through the downstream end of Reach B at the location of the pipeline crossing. Field observations indicate a cascade over the elevated pipe during low flow conditions. At higher flows, the pipelines effect on flow structure becomes less significant.[11]

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[9] The post-emergency measures removed significant volumes of debris and large wood from this section. This material, not considered in the model, likely further reduced conveyance during the 2005 New Year's Eve storm event.

[10] This is the basis for recommended widening, but not lowering, of the Center Road culvert.

[11] This result is not predicted by the model. The model indicates supercritical flows during large storm events. It is unlikely that the channel flow will remain supercritical during storm events. The profile of the pipe is low (protruding less than 6 inches above the bed) and sediment waves will traverse the feature.

TABLE 3: SURVEYED VINEYARD CREEK SLOPES

Cross Section Location	Station (ft)	Elevation ft, NGVD)	Slope (ft/ft)	Reach End Points	Notes
Entire Project Reach			***0.0051***	***A1-C11***	
A1	5000	40.96	0.0034	A1-CRC	
Center Road	4355	38.75			Culvert
B1	4261	37.54	0.0046	A1-B1	
B6	3626	35.70	0.0029	B1-B6	Utility Crossing
B7	3528	33.60	0.0140	B6-C1	
B8	3461	32.94	0.0071	B7-C1	
C1	3421	32.84	0.0056	B1-C1	
C11	2446	28.05	0.0049	C1-C11	
Mc Clay Rd	2440	28.05	0.0049	C1-McClay	Culvert
D1	2368	23.41	0.0499	McClay-D3	
D3	2328	22.46			

6.6. Vegetation Impacts

To examine the flow conveyance impacts of re-establishing riparian vegetation through the corridor, we compared predicted water surface profiles for model simulations over a wide range of bank roughness values. The higher the roughness value, the more flow resistance offered by the bank vegetation. Table 2 presents the assumed roughness values. KHE increased roughness values above the Q2 flow line, where it is assumed County Flood Control will not undertake regular maintenance.[12]

As expected, predicted water surface elevations increase with increasing channel resistance. Flow velocity and stream power decrease with increasing bed and bank roughness. Figures 8A through 8D illustrate the predicted peak flow water-surface profiles over the potential range of vegetation densities. In general, the existing channel configuration under both current and future conditions is able to convey flows up to the Q100 below the Center Road culvert. Upstream of the Center Road Culvert, flooding is predicted at Q50 & Q100 flows at cross-sections A4 and A5.[13] In the Overgrown Conditions (OC) simulations, flooding is predicted at flows equal to or exceeding Q10. OC flooding occurs both upstream (Reach A) and downstream (Reach B) of the Center Road culvert.[14] The changes in the Q50 channel velocities (Figure 8E) also illustrate the predicted impact of revegetation on flow. The most significant velocity reductions occur at the Reach C Narrows, the Rena Court turn, and above the Center Road culvert. The loss of velocity in the Reach C Narrows illustrates the conveyance limit this section poses.[15] We address these flow limiters in the evaluation of channel modification opportunities.

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[12] Regular maintenance assume periodic removal of debris, sediment etc. to maintain conveyance area.
[13] This places a high priority on culvert replacement for the corridor.
[14] N.B. This does not represent storm conditions; it assumes a larger channel cross-section.
[15] Center Road culvert velocity changes are due, in part, to changes from open to closed pipe flow. The largest velocity shifts are at a highpoint in the bed where the model predicts supercritical flow. Contrary to

7. EVALUATION OF CHANNEL MODIFICATION OPPORTUNITIES:

The benefits and impacts of proposed channel modification measures were evaluated through comparative analysis of model results. Expected future [re-vegetated] conditions (FC) serves as the baseline for evaluation of proposed (by reach) modifications. The alternatives evaluated reflect discussion with County Staff and input from local residents.

7.1: Reach A: Arbor Circle to Center Road

The existing conditions analysis indicates the Center Road culvert limits flood conveyance, and is overtopped during greater than 50-year storm events. To ameliorate this impact we recommend an increase in the culvert width. Increased depth is not recommended, to avoid destabilizing the adjacent channel.[16] Alternative widths chosen represent 25% and 50% increases in flow area. No changes to the existing invert elevations are recommended. Table 4 summarizes the existing and evaluated culvert geometries.

**TABLE 4: CENTER ROAD CULVERT:
EXISTING AND PROPOSED DIMENSIONS**

	Shape	Span (ft)	Rise (ft)	Area (ft^2)
Existing Conditions	Box	16	5.13	82.08
25% Increased Flow Area	Box	20	5.13	102.6
50% Increased Flow Area	Box	24	5.13	123.1

Simulation results for 50-year and 100-year peak flows illustrate the potential benefits of increasing culvert size. At Q50 flows (Figure 9), a 25% increase in culvert cross-sectional area provides some reduction in flooding just above the structure, but does not prevent overtopping of the culvert or flooding further upstream in Reach A. Increasing culvert flow area by 50% (Figure 10a) allows passage of the Q50 flows, but does not eliminate flooding in the middle of Reach A. At Q100 flows, neither increase in culvert geometry is sufficient to prevent the overtopping of the culvert or flooding upstream in Reach A. In general, widening the culverts provides localized flood relief. However, the maximum feasible culvert width is approximately 20 ft (a 4-ft increase in width and 31% increase in Q50 flow area) due to constraints posed by adjacent properties. As such, greater benefits may be realized by replacing the culvert with a higher, bridged section that does not restrict flow and sediment transport during peak flows.

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model predictions, we do not expect this point of rapid flow transition to significantly effect flow structure when sediment transport is considered.

[16] The culvert bottom controls the base level in Reach A. Lowering the culvert would likely create bed and bank destabilization upstream (Reach A) and downstream (Reach B).

KHE evaluated changes in flood impacts associated with replacing the culvert with a free-span bridge or arched span to reduce impediments to flow across Center Road. The bridge section assumed maintains the existing16-ft channel width, and the free span permits a 1.2 ft increase in the structures rise (Rise =6.3 ft). KHE minimized other changes in channel cross-section through the transition. The result is a 44% increase in the Q50 flow area at Center Road. Figure 10b-e illustrates the predicted changes in Q50 and Q100 water surface profiles.

The Center Road crossing with an open bridge span passes both the Q50 and Q100 flows without overtopping the structure or the adjacent banks. This alternative provides a greater flood hazard reduction for both upstream and downstream reaches and provides the greatest sediment transport conveyance capacity. At cross-sections A4 and A5, the hydraulic model predicts flooding at both 50-year and 100-year flood elevations. A longitudinal profile of the reach indicates that the top of the bank dips slightly (approximately 1 to 2 feet) at these locations allowing floodwaters to inundate over-bank areas (Figure 11). To preclude this flooding, KHE proposes a 2-foot increase in the "top of bank" elevation in these locations.[17] This increase in left and right bank height is sufficient to prevent flooding upstream of the Center Road culvert. Based on the modeling results, this modification to the bank eliminates over-bank flows, and yielded negligible changes in the predicted water surface profile.

7.2: Reach B: Center Road to Rena Court:

To reduce flooding potential in Reach B, channel modification alternatives considered include:

- B1. Widening the Q2 flood plain and setting back the Wilmac Avenue wall along right bank;
- B2. Lowering the Wilmac Avenue wall; and,
- B3. Constructing a berm along the left bank along the property lines of the adjacent McKeon Court homes.

The County requested evaluation of these alternatives. Simulation results for existing and future conditions indicate that, in Reach B, the existing channel cross-section is sufficient to convey the 50-year (Figures 12 and 13) and 100-year (Figures 14 and 15) peak flows without overtopping the banks. As such, the need for additional measures in the reach is less than anticipated during alternatives development. We did not evaluate Alternatives B2 and B3, described above, using the hydraulic model because the channel changes proposed were above the predicted 50-year water surface elevation through the reach.

To evaluate the potential benefits of Alternative B1, KHE compared predicted water surface profiles for future conditions with and without a 12-foot flood terrace at the

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[17] Additional modifications to the local drainage pattern may need to be integrated to provide passive drainage for the adjacent residences during storm events. Additional survey data will be required to determine parcel specific drainage needs.

anticipated Q2 water level. To accommodate this increased width, we assumed the Wilmac Avenue wall was set back (toward the centerline of the street) a comparable 12-foot distance. Figure 16 illustrates the modifications made to cross-sections B1 through B6. Changes in the predicted Q50 water surface profile were much less than anticipated (Figure 17). Immediately downstream of the Center Road culvert, water levels did decrease slightly (0.5 ft), but because the model predicts super critical flow over the utility crossing at Section B-6, channel widening produces a slight (0.25 ft) increase in the predicted water surface immediately upstream of this section. This increase in floodwater surface occurs at the cross-section where peak flows are closest to the top of bank (within 1 foot), decreasing freeboard to an estimated 0.5 ft. Based on these results, the Q2 terrace widening does not provide a significant amount of flood risk reduction. As such, KHE does not recommend implementation of this alternative.

NOTE: A greater reduction in water levels through the reach requires a further widening of the channel below the predicted Q2 water level. KHE does not recommend this modification for this Vineyard Creek reach. Sediment transport through the reach is high during both intermediate and large storm events. A larger thawed channel could be constructed, but would likely be rapidly filled by sediment. Maintaining a larger channel cross-section would likely increase maintenance costs without adding significant flood reduction benefits.

7.3: Reach C: Rena Court to McClay Road:

KHE evaluated changes in Reach C channel cross sections between Rena Court and McClay road. Proposed channel modifications increase the channel cross-sectional area at reach locations C-3 though C-6. KHE identified this location as a flow constriction point in the Existing Conditions analysis. At these cross-sections the banks are laid back to increase the flow area, and reduce high velocities that drive erosion and bank failure. Figure 18 illustrates the existing and proposed channel cross sections.

Figures 19 and 20 illustrate the changes in the predicted water surface elevations through the reach for the Q50 and Q100 flows. The proposed modifications produce a small (0.25 ft) local decrease in the predicted water surface elevations. The larger cross section also decreases peak flow velocities through the reach, reducing local erosion and bank failure risk. Widening the section also decreases the risk of a debris jam forming at this location during high flow events.

In general, opportunities exist to widen the channel and/or lay back the steep incised banks within Reach C. Appendix A provides modified Reach C cross sectional profiles that reduce bank slopes to 2:1 or less and introduce under-story benches where possible. The cross-sections incorporate a 3-foot wide top of bank flat for maintenance access. Widening of additional Reach C sections may be undertaken to improve bank stability and riparian habitat.

7.4: Reach D: McClay Road to 100-Yards Downstream

No channel or bank modifications are recommended for the reach downstream of the McClay road crossing. The County identified this transition as an impediment to fish passage. A brief discussion of the anticipated measures required to improve fish passage are presented under Corridor Management in Section III.

8. RECOMMENDED CHANNEL MODIFICATIONS

The final “Recommended Modifications,” are based on a cumulative evaluation of measures for all four reaches. Figure 1 illustrates the location of modified features. It incorporates the following activities:

Reach A (Center Road and Upstream):

A1: Increase left and right bank elevations by 2 feet at RS 4798 to 4528 (approximately 300 feet upstream of Center Road).

A2: Widen the Center Road culvert to maximize width and conveyance capacity by constructed a free-span arch or bridge. Do not alter invert elevations.

Reach B (Willmac Avenue to Rena Ct):

No channel modification activities are proposed in this reach.

Reach C (Rena Court to McClay):

C1: Widen channel cross section and reduce bank slopes between RS 3160 and RS 2843 (cross-sections C3-C6).

Reach D (McClay Road and Downstream):

No channel modification activities are proposed in this reach.

Sections 3 and 4 provide a detailed description of these measures and other conclusions and recommendations for management of lower Vineyard Creek. Predicted 50-year and 100-year water surface profiles associated with the set of proposed modifications are presented in Figures 10a-e.

9. REFRENCES

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