Marin Shoreline
Sea Level Rise
Vulnerability Assessment

Bay Waterfront Adaptation & Vulnerability Evaluation
(BayWAVE)
With special thanks to the California State Coastal Conservancy’s Climate Ready Grant Program
Prepared by BVB Consulting for Marin County Department of Public Works
June 2017| County of Marin, CA | marinslr.org

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# Table of Contents

## Table of Contents

Table of Contents ........................................................................................................................................................ i
Figures ..................................................................................................................................................................... viii
Tables ...................................................................................................................................................................... viii
Maps .......................................................................................................................................................................... xi
Acknowledgements.................................................................................................................................................. xiv
List of Acronyms ....................................................................................................................................................... xv
Executive Summary ................................................................................................................................................. xvi
Methods .................................................................................................................................................................. xvii
15-year Expectations .............................................................................................................................................. xviii
Mid Century Expectations........................................................................................................................................ xxi
End of Century Expectations ................................................................................................................................. xxiv
Introduction ................................................................................................................................................................. 1
Methodology ................................................................................................................................................................. 6
Modeling Methods ...................................................................................................................................................... 6
Known Issues ........................................................................................................................................................... 15
Sea Level Rise Maps & FEMA ................................................................................................................................. 18
Assessment Methods .................................................................................................................................................. 18
  Phase 1: Exposure ........................................................................................................................................... 18
  Phases 2 & 3: Sensitivity & Adaptive Capacity ................................................................................................. 19
  Phase 4: Risk & Onset...................................................................................................................................... 20
Other Considerations Methods ................................................................................................................................ 20
ASSET PROFILES ................................................................................................................................................... 23
Asset Profile: Land .................................................................................................................................................... 24
Acres......................................................................................................................................................................... 25
  Near-term: Scenarios 1 &2 ............................................................................................................................... 25
  Medium-term: Scenarios 3 &4 ........................................................................................................................ 26
  Long-term: Scenarios 5 &6 ............................................................................................................................. 26
Vulnerable Parcels.................................................................................................................................................... 27
  Near-term: Scenarios 1&2 ............................................................................................................................. 27
  Medium-term: Scenarios 3 and 4 .................................................................................................................... 29
  Long-term: Scenarios 5 &6 ............................................................................................................................. 30
Landfill Sites ............................................................................................................................................................ 34
Other Considerations................................................................................................................................................ 38
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>38</td>
</tr>
<tr>
<td>Environmental</td>
<td>39</td>
</tr>
<tr>
<td>Social Equity</td>
<td>40</td>
</tr>
<tr>
<td>Management</td>
<td>40</td>
</tr>
<tr>
<td>Asset Profile: Buildings</td>
<td>41</td>
</tr>
<tr>
<td>Structural Factors</td>
<td>42</td>
</tr>
<tr>
<td>Near-term: Scenarios 1 &amp; 2</td>
<td>43</td>
</tr>
<tr>
<td>Flood Depth</td>
<td>45</td>
</tr>
<tr>
<td>Medium-term: Scenarios 3 &amp; 4</td>
<td>45</td>
</tr>
<tr>
<td>Flood Depth</td>
<td>45</td>
</tr>
<tr>
<td>Long-term: Scenarios 5 &amp; 6</td>
<td>47</td>
</tr>
<tr>
<td>Flood Depth</td>
<td>47</td>
</tr>
<tr>
<td>Public Facilities</td>
<td>51</td>
</tr>
<tr>
<td>Schools (Private and Public)</td>
<td>52</td>
</tr>
<tr>
<td>Medical Facilities</td>
<td>52</td>
</tr>
<tr>
<td>Retirement and Assisted Living</td>
<td>53</td>
</tr>
<tr>
<td>Potential Damages</td>
<td>53</td>
</tr>
<tr>
<td>Other Considerations</td>
<td>57</td>
</tr>
<tr>
<td>Economic</td>
<td>57</td>
</tr>
<tr>
<td>Environmental</td>
<td>59</td>
</tr>
<tr>
<td>Social Equity</td>
<td>59</td>
</tr>
<tr>
<td>Management</td>
<td>60</td>
</tr>
<tr>
<td>Asset Profile: Roads, Trails, &amp; Waterways</td>
<td>61</td>
</tr>
<tr>
<td>Transit Service</td>
<td>75</td>
</tr>
<tr>
<td>Bicycling</td>
<td>76</td>
</tr>
<tr>
<td>Water Transportation</td>
<td>77</td>
</tr>
<tr>
<td>Ferry Service</td>
<td>77</td>
</tr>
<tr>
<td>Harbors and Marinas</td>
<td>77</td>
</tr>
<tr>
<td>Airports</td>
<td>78</td>
</tr>
<tr>
<td>Other Considerations</td>
<td>87</td>
</tr>
<tr>
<td>Economic</td>
<td>87</td>
</tr>
<tr>
<td>Environmental</td>
<td>87</td>
</tr>
<tr>
<td>Social Equity</td>
<td>87</td>
</tr>
<tr>
<td>Management</td>
<td>88</td>
</tr>
<tr>
<td>Asset Profile: Water, Wastewater, Stormwater, Gas, Electricity, &amp; Telecommunications</td>
<td>89</td>
</tr>
<tr>
<td>Potable Water</td>
<td>90</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Marin Water District (NMWD)</td>
<td>90</td>
</tr>
<tr>
<td>Marin Municipal Water District (MMWD)</td>
<td>90</td>
</tr>
<tr>
<td>Sewer Service</td>
<td>93</td>
</tr>
<tr>
<td>Sewerage Agency of Southern Marin (SASM)</td>
<td>94</td>
</tr>
<tr>
<td>Sausalito Marin City Sanitary District (SMCSD)</td>
<td>95</td>
</tr>
<tr>
<td>Sanitary District No. 2</td>
<td>96</td>
</tr>
<tr>
<td>Las Gallinas Valley Sanitary District (LGVSD)</td>
<td>96</td>
</tr>
<tr>
<td>Ross Valley Sanitary District</td>
<td>96</td>
</tr>
<tr>
<td>San Rafael Sanitation District</td>
<td>96</td>
</tr>
<tr>
<td>Sanitary District No. 5</td>
<td>96</td>
</tr>
<tr>
<td>Novato Sanitary District</td>
<td>97</td>
</tr>
<tr>
<td>On-site Waste Water Treatment (OWTS)</td>
<td>97</td>
</tr>
<tr>
<td>Fuels (Home and Automotive)</td>
<td>100</td>
</tr>
<tr>
<td>Electricity</td>
<td>101</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>104</td>
</tr>
<tr>
<td>Stormwater Systems</td>
<td>104</td>
</tr>
<tr>
<td>Other Considerations</td>
<td>109</td>
</tr>
<tr>
<td>Economic</td>
<td>109</td>
</tr>
<tr>
<td>Environmental</td>
<td>109</td>
</tr>
<tr>
<td>Social Equity</td>
<td>109</td>
</tr>
<tr>
<td>Management</td>
<td>109</td>
</tr>
<tr>
<td>Asset Profile: Agriculture</td>
<td>110</td>
</tr>
<tr>
<td>Other Considerations</td>
<td>111</td>
</tr>
<tr>
<td>Economic</td>
<td>111</td>
</tr>
<tr>
<td>Environment</td>
<td>111</td>
</tr>
<tr>
<td>Social Equity</td>
<td>111</td>
</tr>
<tr>
<td>Management</td>
<td>111</td>
</tr>
<tr>
<td>Asset Profile: Habitats &amp; Wildlife</td>
<td>112</td>
</tr>
<tr>
<td>Beaches</td>
<td>113</td>
</tr>
<tr>
<td>Tidal Estuaries, Wetlands, &amp; Marshes</td>
<td>114</td>
</tr>
<tr>
<td>Bay</td>
<td>115</td>
</tr>
<tr>
<td>Freshwater Resources</td>
<td>116</td>
</tr>
<tr>
<td>Wildlife &amp; Endangered Species</td>
<td>117</td>
</tr>
<tr>
<td>Mammals</td>
<td>117</td>
</tr>
<tr>
<td>Fish</td>
<td>118</td>
</tr>
<tr>
<td>Birds</td>
<td>119</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insects</td>
<td>120</td>
</tr>
<tr>
<td>Plants</td>
<td>120</td>
</tr>
<tr>
<td>Other Considerations</td>
<td>126</td>
</tr>
<tr>
<td>Economic</td>
<td>126</td>
</tr>
<tr>
<td>Environmental</td>
<td>126</td>
</tr>
<tr>
<td>Social Equity</td>
<td>126</td>
</tr>
<tr>
<td>Management</td>
<td>126</td>
</tr>
<tr>
<td>Asset Profile: Recreation &amp; Public Access</td>
<td>128</td>
</tr>
<tr>
<td>Beaches</td>
<td>132</td>
</tr>
<tr>
<td>Estuaries, Wetlands, &amp; Marshes</td>
<td>132</td>
</tr>
<tr>
<td>Freshwater Resources</td>
<td>132</td>
</tr>
<tr>
<td>Federal Parks</td>
<td>133</td>
</tr>
<tr>
<td>Bay</td>
<td>133</td>
</tr>
<tr>
<td>Sporting Facilities</td>
<td>135</td>
</tr>
<tr>
<td>Bikeways and Trails</td>
<td>135</td>
</tr>
<tr>
<td>Private Recreation</td>
<td>136</td>
</tr>
<tr>
<td>Other Considerations</td>
<td>142</td>
</tr>
<tr>
<td>Economic</td>
<td>142</td>
</tr>
<tr>
<td>Environmental</td>
<td>142</td>
</tr>
<tr>
<td>Social Equity</td>
<td>142</td>
</tr>
<tr>
<td>Management</td>
<td>142</td>
</tr>
<tr>
<td>Asset Profile: Emergency Services</td>
<td>143</td>
</tr>
<tr>
<td>Sheriff</td>
<td>143</td>
</tr>
<tr>
<td>Fire Protection &amp; Emergency Medical</td>
<td>143</td>
</tr>
<tr>
<td>Local Police</td>
<td>144</td>
</tr>
<tr>
<td>California High Patrol (CHP)</td>
<td>144</td>
</tr>
<tr>
<td>Emergency Shelters</td>
<td>144</td>
</tr>
<tr>
<td>Other</td>
<td>144</td>
</tr>
<tr>
<td>Other Considerations</td>
<td>148</td>
</tr>
<tr>
<td>Economic</td>
<td>148</td>
</tr>
<tr>
<td>Environmental</td>
<td>148</td>
</tr>
<tr>
<td>Social Equity</td>
<td>148</td>
</tr>
<tr>
<td>Management</td>
<td>148</td>
</tr>
<tr>
<td>Asset Profile: Cultural Resources</td>
<td>149</td>
</tr>
<tr>
<td>Vulnerable Assets</td>
<td>150</td>
</tr>
<tr>
<td>Archaeological Sites</td>
<td>150</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

Fort Baker ...................................................................................................................................................... 151
Sausalito ............................................................................................................................................................ 152
Marinship, Sausalito ....................................................................................................................................... 152
Belvedere ......................................................................................................................................................... 153
Tiburon ............................................................................................................................................................. 154
Angel Island ...................................................................................................................................................... 154
Larkspur ........................................................................................................................................................... 155
San Rafael ....................................................................................................................................................... 155
Hamilton Army Air Field .................................................................................................................................. 156
Other Considerations ..................................................................................................................................... 159
  Economic ...................................................................................................................................................... 159
  Environmental .......................................................................................................................................... 159
  Social Equity ............................................................................................................................................ 159
  Management ............................................................................................................................................. 159
BayWAVE ....................................................................................................................................................... 163
COMMUNITY PROFILES ............................................................................................................................. 163
Municipality Profile: Sausalito .......................................................................................................................... 164
Vulnerable Assets ........................................................................................................................................... 165
  Land .......................................................................................................................................................... 165
  Buildings .................................................................................................................................................. 166
  Transportation ....................................................................................................................................... 169
  Utilities .................................................................................................................................................... 172
  Working Lands ..................................................................................................................................... 172
  Natural Resources ................................................................................................................................. 172
  Recreation ............................................................................................................................................... 173
  Emergency Services ............................................................................................................................... 174
  Cultural Resources ................................................................................................................................. 180
Community Profile: Mill Valley .......................................................................................................................... 182
Vulnerable Assets ........................................................................................................................................... 183
  Land .......................................................................................................................................................... 183
  Buildings .................................................................................................................................................. 185
  Transportation ....................................................................................................................................... 188
  Utilities .................................................................................................................................................... 193
  Natural Resources ................................................................................................................................. 193
  Recreation ............................................................................................................................................... 194
  Emergency Services ............................................................................................................................... 194
TABLE OF CONTENTS

Cultural Resources ................................................................................................................................. 194
Community Profile: Belvedere .................................................................................................................. 198
Vulnerable Assets ....................................................................................................................................... 198
  Land ................................................................................................................................................ 199
  Buildings ....................................................................................................................................... 200
  Transportation ................................................................................................................................. 203
  Utilities ............................................................................................................................................ 205
  Natural Resources .......................................................................................................................... 205
  Recreation ....................................................................................................................................... 205
  Cultural Resources ........................................................................................................................ 206
  Emergency Services ....................................................................................................................... 206
Community Profile: Tiburon ........................................................................................................................ 210
Vulnerable Assets ....................................................................................................................................... 211
  Land ............................................................................................................................................. 211
  Buildings ....................................................................................................................................... 212
  Transportation ............................................................................................................................... 215
  Utilities ............................................................................................................................................ 218
  Natural Resources ........................................................................................................................ 218
  Recreation ....................................................................................................................................... 218
  Emergency Services ....................................................................................................................... 223
  Cultural Resources ........................................................................................................................ 223
Community Profile: Corte Madera ............................................................................................................. 224
Vulnerable Assets ....................................................................................................................................... 225
  Land ............................................................................................................................................. 225
  Buildings ....................................................................................................................................... 226
  Transportation ............................................................................................................................... 229
  Utilities ............................................................................................................................................ 232
  Natural Resources ........................................................................................................................ 232
  Recreation ....................................................................................................................................... 233
  Emergency Services ....................................................................................................................... 233
  Cultural Resources ........................................................................................................................ 233
Community Profile: Larkspur ..................................................................................................................... 241
Vulnerable Assets ....................................................................................................................................... 242
  Land ............................................................................................................................................. 242
  Buildings ....................................................................................................................................... 243
  Transportation ............................................................................................................................... 247
# TABLE OF CONTENTS

Utilities .................................................................................................................................................. 250
Natural Resources ............................................................................................................................... 250
Recreation ........................................................................................................................................... 250
Emergency Services .......................................................................................................................... 250
Cultural Resources ............................................................................................................................ 250
Community Profile: San Rafael ........................................................................................................ 259

Vulnerable Assets .................................................................................................................................. 260
Land ..................................................................................................................................................... 260
Buildings ............................................................................................................................................. 262
Transportation ..................................................................................................................................... 265
Utilities ................................................................................................................................................. 272
Natural Resources ............................................................................................................................... 272
Recreation ........................................................................................................................................... 272
Emergency Services .......................................................................................................................... 272
Cultural Resources ............................................................................................................................ 277

Community Profile: Novato ................................................................................................................. 280

Vulnerable Assets .................................................................................................................................. 281
Land ..................................................................................................................................................... 281
Buildings ............................................................................................................................................. 282
Transportation ..................................................................................................................................... 285
Utilities ................................................................................................................................................. 290
Working Lands .................................................................................................................................... 290
Natural Resources ............................................................................................................................... 290
Recreation ........................................................................................................................................... 290
Emergency Services .......................................................................................................................... 294
Cultural Resources ............................................................................................................................ 294

Community Profile: Unincorporated Marin........................................................................................... 296

Vulnerable Assets .................................................................................................................................. 297
Land ..................................................................................................................................................... 298
Buildings ............................................................................................................................................. 301
Transportation ..................................................................................................................................... 312
Utilities ................................................................................................................................................. 321
Working Lands .................................................................................................................................... 331
Natural Resources ............................................................................................................................... 332
Recreation ........................................................................................................................................... 332
Emergency Services .......................................................................................................................... 339
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>Tiburon Vulnerable Parcels at MHHW</td>
<td>211</td>
</tr>
<tr>
<td>77</td>
<td>Tiburon Vulnerable Residential and Commercial Parcels</td>
<td>211</td>
</tr>
<tr>
<td>78</td>
<td>Tiburon Vulnerable Parcels by Land Use</td>
<td>211</td>
</tr>
<tr>
<td>79</td>
<td>Tiburon Vulnerable Buildings</td>
<td>212</td>
</tr>
<tr>
<td>80</td>
<td>Tiburon Vulnerable Buildings Average Flood Depth* Estimates at MHHW</td>
<td>213</td>
</tr>
<tr>
<td>81</td>
<td>Tiburon Vulnerable Buildings FEMA Hazus Damage Cost* Estimates for Long-term Scenario 6</td>
<td>213</td>
</tr>
<tr>
<td>82</td>
<td>Tiburon Vulnerable Transportation Assets</td>
<td>215</td>
</tr>
<tr>
<td>83</td>
<td>Example Tiburon Vulnerable Assets by Onset and Flooding at MHHW</td>
<td>223</td>
</tr>
<tr>
<td>84</td>
<td>Corte Madera Exposed Acres</td>
<td>225</td>
</tr>
<tr>
<td>85</td>
<td>Corte Madera Vulnerable Parcels at MHHW</td>
<td>225</td>
</tr>
<tr>
<td>86</td>
<td>Corte Madera Vulnerable Parcels by Land Use</td>
<td>226</td>
</tr>
<tr>
<td>87</td>
<td>Corte Madera Vulnerable Residential and Commercial Parcels</td>
<td>226</td>
</tr>
<tr>
<td>88</td>
<td>Corte Madera Vulnerable Buildings by Scenario</td>
<td>227</td>
</tr>
<tr>
<td>89</td>
<td>Corte Madera Vulnerable Buildings Average Flood Depths* at MHHW</td>
<td>227</td>
</tr>
<tr>
<td>90</td>
<td>Corte Madera Vulnerable Buildings’ FEMA Hazus Storm Damage Cost* Estimates in Long-term Scenario 6</td>
<td>227</td>
</tr>
<tr>
<td>91</td>
<td>Corte Madera Vulnerable Transportation Assets</td>
<td>230</td>
</tr>
<tr>
<td>92</td>
<td>Example Corte Madera Vulnerable Assets by Sea Level Rise Onset and Flooding at MHHW</td>
<td>234</td>
</tr>
<tr>
<td>93</td>
<td>Larkspur Exposed Acreage</td>
<td>242</td>
</tr>
<tr>
<td>94</td>
<td>Larkspur Vulnerable Parcels</td>
<td>242</td>
</tr>
<tr>
<td>95</td>
<td>Larkspur Vulnerable Residential and Commercial Parcels</td>
<td>243</td>
</tr>
<tr>
<td>96</td>
<td>Larkspur Vulnerable Parcels by Land Use</td>
<td>243</td>
</tr>
<tr>
<td>97</td>
<td>Larkspur Vulnerable Buildings</td>
<td>244</td>
</tr>
<tr>
<td>98</td>
<td>Larkspur Tidal MHHW Flood Depth Estimates for Vulnerable Buildings</td>
<td>244</td>
</tr>
<tr>
<td>99</td>
<td>Larkspur Vulnerable Buildings FEMA Hazus Storm Damage Cost Estimates in Long-term Scenario 6</td>
<td>244</td>
</tr>
<tr>
<td>100</td>
<td>Larkspur Transportation Routes Vulnerable to Sea Level Rise and a 100-year Storm Surge</td>
<td>248</td>
</tr>
<tr>
<td>101</td>
<td>Example Vulnerable Larkspur Assets by Onset and Flooding at MHHW</td>
<td>251</td>
</tr>
<tr>
<td>102</td>
<td>San Rafael Exposed Acres</td>
<td>260</td>
</tr>
<tr>
<td>103</td>
<td>San Rafael Vulnerable Residential and Commercial Parcels</td>
<td>261</td>
</tr>
<tr>
<td>104</td>
<td>San Rafael Vulnerable Parcels by Land Uses</td>
<td>261</td>
</tr>
<tr>
<td>105</td>
<td>San Rafael Vulnerable Buildings by Scenario</td>
<td>262</td>
</tr>
<tr>
<td>106</td>
<td>San Rafael Vulnerable Buildings Tidal Flooding* Estimates at MHHW</td>
<td>263</td>
</tr>
<tr>
<td>107</td>
<td>San Rafael Vulnerable Buildings’ FEMA Hazus Storm Damage Cost* Estimates in Long-term Scenario 6</td>
<td>263</td>
</tr>
<tr>
<td>108</td>
<td>San Rafael Vulnerable Transportation Assets</td>
<td>266</td>
</tr>
<tr>
<td>109</td>
<td>Example San Rafael Vulnerable Assets by Sea Level Rise &amp; Flooding at MHHW</td>
<td>277</td>
</tr>
<tr>
<td>110</td>
<td>Novato Vulnerable Acreage</td>
<td>281</td>
</tr>
<tr>
<td>111</td>
<td>Novato Vulnerable Parcels</td>
<td>282</td>
</tr>
<tr>
<td>112</td>
<td>Novato Vulnerable Parcels by Land Use</td>
<td>282</td>
</tr>
<tr>
<td>113</td>
<td>Novato Vulnerable Residential and Commercial Parcels</td>
<td>282</td>
</tr>
<tr>
<td>114</td>
<td>Novato Vulnerable Buildings</td>
<td>283</td>
</tr>
<tr>
<td>115</td>
<td>Novato Tidal MHHW Flood Depth Estimates for Vulnerable Buildings</td>
<td>283</td>
</tr>
<tr>
<td>116</td>
<td>Novato Vulnerable Buildings FEMA Hazus Damage Cost* Estimates</td>
<td>283</td>
</tr>
<tr>
<td>117</td>
<td>Novato Vulnerable Transportation Routes</td>
<td>286</td>
</tr>
<tr>
<td>118</td>
<td>Example Novato Vulnerable Assets by Sea Level Rise Onset and Flooding at MHHW</td>
<td>295</td>
</tr>
<tr>
<td>119</td>
<td>Unincorporated Marin Communities’ Acreage Exposed by BayWAVE Scenario</td>
<td>297</td>
</tr>
<tr>
<td>120</td>
<td>Unincorporated Marin Vulnerable Parcels in the Near-term</td>
<td>299</td>
</tr>
<tr>
<td>121</td>
<td>Unincorporated Marin Vulnerable Parcels in the Medium-term</td>
<td>299</td>
</tr>
<tr>
<td>122</td>
<td>Unincorporated Marin Vulnerable Parcels in the Long-term</td>
<td>300</td>
</tr>
<tr>
<td>123</td>
<td>Unincorporated Marin Vulnerable Buildings in the Near-term</td>
<td>301</td>
</tr>
<tr>
<td>124</td>
<td>Unincorporated Marin Vulnerable Buildings in the Medium-term</td>
<td>302</td>
</tr>
<tr>
<td>125</td>
<td>Unincorporated Marin Vulnerable Buildings in the Long-term</td>
<td>302</td>
</tr>
<tr>
<td>126</td>
<td>Unincorporated Marin Vulnerable Buildings by Flood Depth at MHHW</td>
<td>310</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

Table 127. Unincorporated Vulnerable Buildings FEMA HAZUS Storm Damage Cost* Estimates in Long-term Scenario 6 .......................................................................................................................... 311
Table 128. Unincorporated Marin Roads Vulnerable to Sea Level Rise and a 100-year Storm Surge ......................... 313
Table 129. Vulnerable Agricultural Parcels and Acreage by Community ............................................................... 331
Table 130. Unincorporated Marin Vulnerable Parks and Facilities ........................................................................ 334
Table 131. Example Unincorporated Marin Vulnerable Assets by Sea Level Rise Onset & Flooding at MHHW ............................................................ 341
Table 132. East Marin Assets Vulnerable to Sea Level Rise and a 100-year Storm Surge .................................. 354
Table 133. Interviewed Agencies and Managers ................................................................................................. 371

Maps

Map 1. BayWAVE Study Area .................................................................................................................................. xv
Map 131. Fifteen-year Expectation: Near-term Vulnerable Assets ........................................................................... xviii
Map 132. Mid-century Expectation: Medium-term Vulnerable Assets ................................................................. xx
Map 133. End of Century Expectations: Long-term Vulnerable Assets ............................................................... xxiv
Map 1. BayWAVE Study Area .................................................................................................................................... 3
Map 2. Northern Study Area Inland Extent of Scenario 6 ........................................................................................ 9
Map 3. Southern Study Area Inland Extent of Scenario 6 ....................................................................................... 10
Map 4. Northern Study Area Sea Level Rise Scenarios ........................................................................................ 11
Map 5. Southern Study Area Sea Level Rise Scenarios ........................................................................................ 12
Map 6. Northern Study Area Sea Level Rise and 100-year Storm Surge Scenarios .............................................. 13
Map 7. Southern Study Area Sea Level Rise and 100-year Storm Surge Scenarios ............................................. 14
Map 8. Northern Study Area Known Issues with CoSMoS Model ........................................................................ 16
Map 9. Southern Study Area Known Issues with CoSMoS Model ............................................................... 17
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### List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
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<tr>
<td>BayWAVE</td>
<td>Bay Waterfront Adaptation and Vulnerability Evaluation</td>
</tr>
<tr>
<td>MHHW</td>
<td>Mean Higher High Water</td>
</tr>
<tr>
<td>GGBHTD</td>
<td>Golden Gate Bridge, Highway and Transportation District</td>
</tr>
<tr>
<td>GGT</td>
<td>Golden Gate Transit</td>
</tr>
<tr>
<td>GGF</td>
<td>Golden Gate Ferry</td>
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<tr>
<td>C-SMART</td>
<td>Collaboration: Sea-Level Marin Adaptation Response Team</td>
</tr>
<tr>
<td>OWTS</td>
<td>On-site Wastewater Treatment System</td>
</tr>
<tr>
<td>CDA</td>
<td>Community Development Agency</td>
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<tr>
<td>DPW</td>
<td>Department of Public Works</td>
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<td>NMWD</td>
<td>North Marin Water District</td>
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<td>Marin Municipal Water District</td>
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<tr>
<td>PG&amp;E</td>
<td>Pacific Gas and Electric</td>
</tr>
<tr>
<td>SASM</td>
<td>Sewerage Agency of Southern Marin</td>
</tr>
<tr>
<td>NSD</td>
<td>Novato Sanitary District</td>
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<tr>
<td>USFWS</td>
<td>United States Fish and Wildlife Service</td>
</tr>
<tr>
<td>CADFW</td>
<td>California Department of Fish and Wildlife</td>
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<tr>
<td>LGVSD</td>
<td>Las Gallinas Valley Sanitary District</td>
</tr>
<tr>
<td>CMSA</td>
<td>Central Marin Sanitation Agency</td>
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<tr>
<td>LHMP</td>
<td>Local Hazard Mitigation Plan</td>
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</table>
Executive Summary

Sea level in the San Francisco Bay Area has risen eight inches in the past century, and could rise up to 70 inches by the end of the century.\(^1\), \(^2\) Marin’s bay shoreline is vulnerable to sea level rise and intensifying storm patterns. The third National Climate Assessment cites strong evidence that the cost of doing nothing exceeds the costs associated with adapting to sea level rise by 4 to 10 times.\(^3\) Therefore, it is critical the County of Marin, incorporated jurisdictions, and special districts plan and prepare for the impacts of sea level rise to ensure a resilient county for present and future generations.

The County of Marin Department of Public Works and Community Development Agency are the project leads for the Bay Waterfront Adaptation & Vulnerability Evaluation (BayWAVE) program. The program began in September 2015 with funding from County of Marin and additional financial support from the California Coastal Conservancy.

Several committees support the BayWAVE process. The Executive Steering Committee consists of County of Marin and local jurisdiction representatives. The Technical Advisory Committee includes staff from local, state, and federal agencies. Lastly, the Policy Committee includes elected officials from the participating jurisdictions. These committees serve as the beginning of the program’s goals to establish an efficient shared learning process and community messaging, and create a collaborative environment for preparing for sea level rise for all shoreline communities, and others inland, that could face the impacts of sea level rise in the coming decades. This effort may also support these communities in collaborating with and benefiting from the larger Bay Area region efforts underway.

The Vulnerability Assessment is an initial effort to identify the risks and exposure from sea level rise. Future tasks could include development of an adaptation report and may occur at different jurisdictions: local municipalities, service districts, and County of Marin could update general plans, master plans, capital improvement plans, hazard mitigation plans, and other relevant plans and procedures in the near future. While this effort focuses on sea level rise, Marin County experiences flooding from creeks, tides, and stormwater. Planning for solutions should evaluate the combined impacts of flooding to best prepare for a range of conditions.

This effort is part of an ongoing scientific and public process to understand and prepare for sea level rise along the shoreline. This Vulnerability Assessment seeks to provide context and estimates of the physical and fiscal impacts across the County of Marin’s bayside shoreline over the coming decades. These data highlight the complexity of the potential impacts and the need for concerted and individual actions in the face of rising tides. The data can be used to prioritize efforts, seek funding, and shape policy and development discussions that will guide the plans mentioned above.

This document presents asset profiles describing the potential consequences of a no-action, or business as usual political environment, especially for existing development. Asset profiles present potential consequences for parcels and buildings, transportation networks, utilities, working lands, natural resources, recreational assets, emergency services, and cultural resources. Vulnerable assets are also presented by jurisdiction in community profiles to enable local professionals, officials, and residents to engage in local discussions and relate to their neighbors. The following exposed and vulnerable communities have community profiles and make up the 85,840 acre study area shown in Map 1.

---


EXECUTIVE SUMMARY

Map 1. BayWAVE Study Area

- Municipalities
  - Belvedere
  - Corte Madera
  - Larkspur
  - Mill Valley
  - Novato
  - San Rafael
  - Sausalito
  - Tiburon

- Unincorporated Jurisdictions
  - Almonte
  - Bayside Acres
  - Bel Marin Keys
  - Black Point
  - California Park
  - Country Club
  - Greenbrae
  - Kentfield
  - Marin City
  - North Novato
  - Paradise Cay
  - Point San Pedro
  - San Quentin
  - Santa Venetia
  - St. Vincent’s

Each profile details key issues and geographic locations. Asset profiles include economic, environmental, equity, and management considerations related to sea level rise vulnerability. Each profile can be read independently of the others, enabling asset managers to focus on their professional area, and community members, elected officials, and others to read the analysis for a community as a whole.

Methods

Table 1 shows the range of sea level rise projections for California adopted by the National Research Council in 2012. Given the uncertainty in the magnitude and timing of future sea level rise, this Assessment uses a scenario based approach to assess a range of potential sea level rise impacts. The scenarios selected for this Vulnerability Assessment are derived from the United States Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS) that combines global climate and wave models with projected sea level rise to identify areas that could be flooded across 10 different sea levels (ranging from 0 to 200 inches) and 4 storm severities (none, annual, 20-, 100-year storm surges) to total 40 possible combinations. All of these scenarios are viewable on the Our Coast Our Future (OCOF) Flood Map website.

One limitation of the model and every sea level rise model available at this time is the failure to combine sea level rise, stormwater drainage, and creeks. The model displays the impacts of flooding from the bay overtopping the shoreline edge and flooding low-lying areas. However, in Marin areas experience the impacts of high tides that coincide with storms, which result in water coming from the hills and the bay. Additionally, underground or low-lying drainage pipes and channels allow water to flood areas where the shoreline edge is sufficiently elevated to prevent direct overtopping. These vulnerabilities are described in the text, but tables and maps show sea level rise as presented in the CoSMoS model.
The findings of this assessment are based on three sea levels and each sea level combined with a 100-year storm surge as shown in Table 2. Scenarios 1 and 2 represent the near-term, and correspond to the 2030 NRC projected sea level range. Scenarios 3 and 4 represent the medium-term and are within the 2050 NRC range. Scenarios 5 and 6 represent the long-term and correspond to the 2100 NRC range. Figure 3 presents another view of the BayWAVE scenario where the red lengths represent tidal flooding in sea level rise scenarios 1, 3, and 5, and the blue lengths represent the addition storm surge water level associated with scenarios 2, 4, and 6. Together these bands show the potential flooding in the near-, medium-, and long-terms.

Vulnerability is based on an asset’s exposure, sensitivity, and adaptive capacity to rising bay waters and storm surge threats. If an exposed asset is moderately or highly sensitive to sea level rise impacts, with low to no adaptive capacity, the asset is considered vulnerable. Vulnerable assets may be vulnerable to flooding and/or increased rates of subsidence over the coming decades. Extensive geographic mapping was conducted overlapping layers of assets from MarinMap and sea level rise extent and flood depth layers to determine exposure. To ascertain sensitivity and adaptive capacity, the project team interviewed 115 asset managers, for example, the heads of public works departments, using the BayWAVE Asset Vulnerability Assessment Tool to assess more than 350 built and natural resource assets. The interview results were combined with the geographic data to develop the Vulnerability Assessment.

<table>
<thead>
<tr>
<th>Table 1. Sea Level Rise Projections for San Francisco, CA Region</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time Period</strong></td>
</tr>
<tr>
<td>by 2030</td>
</tr>
<tr>
<td>by 2050</td>
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<tr>
<td>by 2100</td>
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</table>

15-year Expectations

Sea level rise flooding could reduce useable living space and adversely affect tourism, transportation, and natural attractions and resources within 15 years. The first threats are to buildings, roads, and original utility systems along the shoreline. Disruptive flooding to the road and utility networks could have regional ripple effects for extended periods of time. In the near-term, San Rafael and Southern Marin shoreline communities are most at risk to tidal and storm surge flooding.
In this near-term timeframe, tidal flooding at 10 inches of sea level rise (MHHW) could reach 5,000 acres, 1,300 parcels, and 700 buildings, potentially impacting tens of thousands of residents, employees, and visitors. Regular tidal flooding could adversely impact San Rafael east of US Highway 101, bayfront Belvedere and Tiburon, Greenbrae Boardwalk, Waldo Point, and Paradise Cay.

With an additional 100-year storm surge, the previously impacted acres, parcels, and buildings could face tidal and storm surge flooding. An additional 3,000 acres, 2,500 parcels, and 3,800 buildings could anticipate storm surge flooding. These figures amount to six percent of parcels and buildings in the study area. Storm surge flooding, could impact North Novato at Gnoss Field, Black Point on the Petaluma River, lower Santa Venetia, Belvedere around the lagoon, bayfront Corte Madera, bayfront Mill Valley, Marinship in Sausalito, Tamalpais, and Almonte, in addition to the communities vulnerable to tidal flooding.

Eight miles of road could expect tidal flooding. Many of these flooded areas already experience seasonal and king tide flooding. These are:

- Manzanita, Almonte
- Miller Avenue in Mill Valley,
- the Marinship area in Sausalito,
- US Highway 101 in Marin City, Corte Madera, Larkspur, and
- State Route 37 in Novato.

This is expected to worsen in severity and become increasingly frequent. Tidal flooding would reach the Canal area of San Rafael, spreading to I-580. Several roads in Santa Venetia, Tamalpais, Belvedere, Mill Valley, Marin Lagoon of San Rafael, and bayfront Corte Madera and Larkspur would begin to experience seasonal, king tide, and storm surge flooding more frequently.

Water travel infrastructure could be compromised at ferry facilities in Larkspur, Tiburon, and Sausalito preventing commuters from traveling to work. Even if the facilities are able to handle near-term higher tides, providing safe parking and access to ferry users could prove challenging. Smaller public and private and marinas and boat launches along the bay in Sausalito, Mill Valley, Strawberry, Tiburon, Belvedere, Bel Marin Keys, and Black Point could be flooded out and unusable. Storm surges can be powerful enough to damage and sink boats. This is especially a concern for residential boats.

Southern Marin Fire Protection and Sausalito Police Department boats are included in the boats harbored in marinas vulnerable to sea level rise. The Castro Fire Station in San Rafael is vulnerable to tidal flooding in the near-term and the California Highway Patrol offices in Corte Madera could expect storm surge flooding in this time period. Most concerning, however; is the potential inability of emergency professionals and vehicles to access people in or through flooded areas.

In addition, the marshlands that buffer the shoreline communities from high tides and storm surges could begin to experience transitions in habitat, especially those in Southern Marin where they are typically bordered by urban development. Consequently, the waters here would get deeper and flood out the existing habitat, shifting high marsh to low marsh, low marsh to mud flat, and mud flats to open water. Without adequate light of shallow water, eelgrass beds would shrink. Collectively, these habitat shifts could have significant impacts on vulnerable species such as the salt marsh harvest mouse, Ridgway’s Rail, or the long-fin smelt.
In 15 years, high tides could threaten Marin’s shoreline buildings, roads, and original utility systems. Damage and breakdowns in road and utility networks would impact the entire County, especially Southern Marin. Tidal flooding (red) could reach 5,000 acres, 1,300 parcels, 700 buildings, and 8 miles of road in San Rafael east of State Route 101, bayfront Belvedere and Tiburon, Greenbrae Boardwalk, Waldo Point, and Paradise Cay. A 100-year storm surge (pink) would flood these areas with storm surge flooding, and flood an additional 3,000 acres, 2,500 parcels, 3,800 buildings, and 20 miles of road in North Novato, Black Point on the Petaluma River, lower Santa Venetia, Belvedere Lagoon, bayfront Corte Madera and Mill Valley, Marinship in Sausalito, Marin Lagoon in San Rafael, Tamalpais, and Almonte. Flooded ferry facilities would prevent commuters and visitors from traveling across the Bay. Boating facilities in Sausalito, Mill Valley, Strawberry, Tiburon, Belvedere, San Rafael, Bel Marin Keys, and Black Point may be inaccessible. This is especially a concern for marinas with residential boats and Southern Marin Fire and Sausalito Police boats. The Castro St. Fire Station in San Rafael is vulnerable to tidal flooding, though all emergency professionals would be denied vehicular access to people in vulnerable areas. Southern Marin marshlands would shift high marsh to low marsh to mud flat, and eelgrass beds could shrink under deeper darker waters. These habitat shifts would have significant repercussions for plant, insect, fish, and animal species.
**EXECUTIVE SUMMARY**

**Mid Century Expectations**

In this medium-term timeframe, tidal flooding at 20 inches of sea level rise (MHHW) could reach nearly 7,000 acres, 3,000 parcels, and 2,000 buildings, potentially impacting even more residents, employees, and visitors than in the near-term. Regular high tide tidal flooding could adversely impact the same locations tidally flooded in the near-term, though more severely.

With an additional 100-year storm surge, the previously impacted acres, parcels, and buildings could face tidal and storm surge flooding, and an additional 7,000 acres, 2,200 parcels, and 3,600 buildings could anticipate storm surge flooding. These figures amount to eight percent of parcels and seven percent of buildings in the study area. Most levees south of Novato are not designed to withstand this level of flooding and could be overtopped. Storm surge flooding would impact the same locations as in near-term scenario 2, 10 inches with a 100-year storm surge, and extends further inland beyond the marshy areas of Mill Valley, Strawberry, San Rafael, St. Vincent’s, and North Novato.

Eighteen miles of roadway, ten more miles than in the near-term, could expect tidal flooding. Many of the impacted roads are the same as those impacted in the near-term, though much greater lengths could anticipate tidal flooding and flooding depths would increase. Storm surge flooding could reach a total of 44 additional miles of roadway. Water travel could experience similar outcomes as in the near-term, though the highest high tides and storms surges would cause even more damage than weathered twenty years earlier.

With respect to utilities, pipelines under vulnerable roads, and lateral pipes to vulnerable properties, would become squeezed between rising groundwater and the confining roadway. This could cause pipes to bend and break, and could even damage roadways. In the medium-term, impacts to the North Marin Water District service area would impact water service in Bel Marin Keys and unincorporated Novato. In fact, Bel Marin Keys already experiences seasonal saltwater contamination. Vulnerable substations, electrical transmission towers and lines, and underground natural gas pipelines along the shoreline would be compromised by flooding and subsidence. Disruptions or failures in this network could also have far reaching impacts in transportation, sanitary

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**IMPACTS AT-A-GLANCE: SCENARIO 4**

<table>
<thead>
<tr>
<th>6,700 acres flooded @ MHHW</th>
<th>200,000+ residents plus commuting employees</th>
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<tbody>
<tr>
<td>13,500 acres flooded @ MHHW +100-year storm surge</td>
<td>2,000 agricultural acres (mostly ranch)</td>
</tr>
<tr>
<td>5,600 homes, businesses, &amp; institutions</td>
<td>Property Owners County of Marin Municipalities Caltrans Sanitary Districts Water Districts Fire Districts Sausalito Police Department CHP SMART GGBHTD MTA PG&amp;E AT&amp;T CA DFW</td>
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<tr>
<td>62 miles of wet road, 3 ferry landings, 5 marinas, 4 boat launches</td>
<td>Beaches Tidal Marshes Creeks Eelgrass beds Ponds Wetlands</td>
</tr>
</tbody>
</table>

*King tides preview future water levels. Mill Valley. 10:41 a.m., Nov. 25, 2015. Credit: Light Hawk Aerial*
service, stormwater management facilities, food storage, communications, and general public safety.

This twenty inch increase in sea level would continue to shrink Southern Marin, Tiburon Peninsula, and Pt. San Pedro marsh and tidal habitats. Complimentary recreational trails, parks, athletic facilities would experience reductions in capacity with increases in maintenance costs.

*Mill Valley-Sausalito Path. Credit: J. Poskazner*

*Historic Flood on US Highway 101 and fronting marshes. Larkspur. Credit: Marin DPW*
Tidal flooding could reach 7,000 acres, 3,000 parcels, 2,000 buildings, and 18 miles of roadway in the same locations impacted in the near-term, though more severely. With a 100-year storm surge, the area vulnerable to tidal flooding would also experience storm surge flooding. An additional 7,000 acres, 2,200 parcels (8%), 3,600 buildings (7%), and 40 miles of roadway could anticipate storm surge flooding. Most levees south of Novato are not designed to withstand this level of flooding and would be overtopped. Storm surge flooding would extend further inland beyond the marshy areas of Mill Valley, Strawberry, San Rafael, St. Vincent’s, and North Novato. Water travel could experience similar outcomes as in the near-term, though the highest tides and storm surges would cause even more damage than weathered twenty years earlier. Pipelines beneath flooded roads could become squeezed between rising groundwater and the roadway, cause pipes to bend and break, and even damage roadways, this is true for PG&E substations, electrical transmission towers and lines, and natural gas pipelines could be bent or broken by flooding, subsidence, and erosion, with far reaching impacts on utilities, buildings, and transportation. This ten inch increase in sea level would continue to shrink trapped beach and marsh habitats in Southern Marin. Shoreline parks and pathways would flood often.
EXECUTIVE SUMMARY

IMPACTS AT-A-GLANCE: SCENARIO 6

<table>
<thead>
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<th>16,300 acres flooded @ MHHW</th>
<th>200,000+ residents plus commuting employees</th>
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<td>18,000 acres flooded @ MHHW +100-year storm surge</td>
<td>4,150 agricultural acres (mostly ranch)</td>
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<tr>
<td>12,100 homes, businesses, &amp; institutions</td>
<td>Property Owners County of Marin Municipalities Caltrans Sanitary Districts Water Districts Fire Districts Sausalito &amp; Central Marin Police Departments CHP SMART GGBHTD MTA PG&amp;E AT&amp;T CADFHW</td>
</tr>
<tr>
<td>$15.6 billion in assessed property value⁴</td>
<td>200 miles of wet road, 3 ferry landings, 5 marinas, 4 boat launches</td>
</tr>
<tr>
<td>Beaches Tidal Marshes Creeks Eelgrass beds Ponds Wetlands</td>
<td></td>
</tr>
</tbody>
</table>

End of Century Expectations

In this long-term timeframe, tidal flooding at 60 inches of sea level rise (MHHW) could reach nearly 7,000 acres, 8,000 parcels, and 9,000 buildings, potentially impacting hundreds of thousands of residents, employees, and visitors. These figures amount to 13 percent of parcels and 12 percent of buildings in the study area. Regular tidal flooding could adversely impact the same locations impacted in the near- and medium-terms and significant portions of what would have previously only flooded from the 100-year storm surge. The additional areas that would tidally flood at 60 inches of sea level rise are:

- Tamalpais Valley,
- Mill Valley from the Richardson’s Bay shoreline up to and beyond Camino Alto between Miller and East Blithedale Avenues,
- Mill Valley and Strawberry fronting US Highway 101 between Seminary Drive and Tiburon Boulevard,
- Santa Venetia north of N. San Pedro Boulevard,
- Cove Neighborhood, Tiburon,
- Belvedere Lagoon neighborhood,
- Paradise Cay
- Mariner Cove, Marina Village, Madera Gardens, and major retail centers lining US Highway 101,
- Riviera Circle, Creekside, and Heatherwood neighborhoods, Larkspur,
- Interstate 580 and westward towards Andersen Drive in San Rafael and the community of California Park,
- Marin Lagoon and Peacock Gap neighborhoods, San Rafael,
- Bel Marin Keys northern and southern lagoon areas,
- Hamilton, Vintage Oaks, and pockets of development east of US Highway 101 at Rowland Boulevard and State Route 37 in Novato, and,
- North Novato at US Highway 101 and Binford Road.

In long-term scenario 6, storm surge flooding could occur on nearly 13,500 acres hosting 12,600 parcels with 12,000 buildings, potentially impacting 200,000 residents, thousands of employees, and several million visitors. These figures amount to nearly one-fifth of parcels and more than 15 percent of the buildings in the study area. Area that could anticipate storm surge flooding are:

- Tamalpais Valley,
- Mill Valley from the Richardson’s Bay shoreline up to and beyond Camino Alto between Miller and East Blithedale Avenues,
- Mill Valley and Strawberry fronting US Highway 101 between Seminary Drive and Tiburon Boulevard,
- Santa Venetia north of N. San Pedro Boulevard,
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- Riviera Circle, Creekside, and Heatherwood neighborhoods, Larkspur,
- Interstate 580 and westward towards Andersen Drive in San Rafael and the community of California Park,
- Marin Lagoon and Peacock Gap neighborhoods, San Rafael,
- Bel Marin Keys northern and southern lagoon areas,
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- Bel Marin Keys northern and southern lagoon areas,
- Hamilton, Vintage Oaks, and pockets of development east of US Highway 101 at Rowland Boulevard and State Route 37 in Novato, and,
- North Novato at US Highway 101 and Binford Road.

In long-term scenario 6, storm surge flooding could occur on nearly 13,500 acres hosting 12,600 parcels with 12,000 buildings, potentially impacting 200,000 residents, thousands of employees, and several million visitors. These figures amount to nearly one-fifth of parcels and more than 15 percent of the buildings in the study area. Area that could anticipate storm surge flooding are:

- Tamalpais Valley,
- Mill Valley from the Richardson’s Bay shoreline up to and beyond Camino Alto between Miller and East Blithedale Avenues,
- Mill Valley and Strawberry fronting US Highway 101 between Seminary Drive and Tiburon Boulevard,
- Santa Venetia north of N. San Pedro Boulevard,
- Cove Neighborhood, Tiburon,
- Belvedere Lagoon neighborhood,
- Paradise Cay
- Mariner Cove, Marina Village, Madera Gardens, and major retail centers lining US Highway 101,
- Riviera Circle, Creekside, and Heatherwood neighborhoods, Larkspur,
- Interstate 580 and westward towards Andersen Drive in San Rafael and the community of California Park,
- Marin Lagoon and Peacock Gap neighborhoods, San Rafael,
- Bel Marin Keys northern and southern lagoon areas,
- Hamilton, Vintage Oaks, and pockets of development east of US Highway 101 at Rowland Boulevard and State Route 37 in Novato, and,
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- Belvedere Lagoon neighborhood,
- Paradise Cay
- Mariner Cove, Marina Village, Madera Gardens, and major retail centers lining US Highway 101,
EXECUTIVE SUMMARY

- Sausalito west of Bridgeway,
- Marin City neighborhood,
- Mill Valley east of East Blithedale Avenue at Alto Shopping Center,
- Las Gallinas and North San Pedro Boulevard, east of US Highway 101, San Rafael,
- Bayside Acres,
- Country Club, and
- Kentfield.

Tidal and storm surge flooding could cause significant economic losses. Minor storm impacts alone could account for $61 million in property damages. The market value of vulnerable single-family homes could exceed $20 billion in 2016 dollars. The assessed value, typically less than market value, for all the vulnerable parcels in the study area is $15.6 billion. By the end of the century, these figures could be even higher.

One-hundred miles of public and private roadways, or five percent of all road miles in the study area, could be vulnerable to tidal exposure. Roads could degrade more quickly, or if flood waters are deep enough, become impassable. Lane miles could be more than double this figure. An additional 30 miles of roadway could be vulnerable at 60 inches of sea level rise and a 100-year storm surge. Moreover, several park and rides, several hundred bus stops, and bus transit and SMART rail routes could flood. The San Rafael Transit Center, where the SMART train and nearly all local and regional buses stop, could expect tidal flooding at MHHW and storm surge flooding in the long-term. Breakdowns in the transportation network would have major impacts on the economy and daily life functions. In addition, significant safety hazards could cause injury or loss of life.

Flooding at the SASM and Novato Sanitary Wastewater Treatment Plants is a significant vulnerability that could arise, potentially disrupting hundreds of thousands of people. By this time, much of the low-lying shoreline sanitary sewer and stormwater infrastructure could be flooded out.

By the end of the century, sea level rise could have direct impacts to Tiburon Fire Station No. 1, Corte Madera Station No. 13, and Novato Atherton Avenue Fire Station. A few emergency shelters in Southern Marin communities could be vulnerable to tidal flooding, and several more could expect storm surge flooding and may not be available when needed most. By this time, the Central Marin Police Department could have to wade through saltwater surrounding the site to reach Larkspur and Corte Madera residents in need.

Southern Marin marshes may no longer exist by the end of the century, destroying the habitat of several shoreline birds and mammals. Northern Marin marshes would become increasingly tidally influenced, with tide water reaching US Highway 101 in Bel Marin Keys and North Novato up the Petaluma River. Typically freshwater marshes west of US Highway 101, for example, Sutton Marsh, could also expect damaging salinity impacts. Tidal marsh lands may increase in Northern Marin if they are not prevented from migrating inland.

In the long-term scenario, approximately 1,358 acres on 30 agricultural parcels could be vulnerable to sea level rise and storm conditions. Another 3,000 acres are public agency lands near Bel Marin Keys, Hamilton Field, and the Novato Sanitary District that are leased for agricultural use. Higher high tides could push brackish conditions inland, reducing grazing, manure spreading, and cultivation area. Moreover, reduced vehicular access on Highways 37, 101, and other major roads could disrupt product distribution.

Finally, all of these assets contain or contribute to the well-being of the region’s cultural, archeological, and historic resources that constitute each community’s sense of place. This is especially a concern for Sausalito, Tiburon, and Novato.

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5 2016 dollars
6 2016 dollars
EXECUTIVE SUMMARY

Map 133. End of Century Expectations: Long-term Vulnerable Assets

By 2100, tidal flooding could reach nearly 7,000 acres, 8,000 parcels (13%), 9,000 buildings (12%), and 100 miles of road. Higher high tides could adversely impact the locations flooded in medium-terms, and significant portions of the areas that previously suffered storm surge flooding. Tidal flooding would reach beyond the State Routes 101 and 80 in low-lying areas, into Southern Marin’s narrow valleys and creek sides, and over every levee in Marin County. A 100-year storm surge could flood these areas, and an additional 8,500 acres, 4,600 parcels (20% total), 3,000 buildings (15% total), and 30 miles of road, extending to Sausalito west of Bridgeway, Marin City housing, Mill Valley’s Alto Shopping Center, Las Gallinas and N. San Pedro Blvd. in San Rafael, Bayside Acres, Country Club, and Kentfield. Minor building damage could amount to $81 million (2019 dollars). Vulnerable single family homes exceed $20 billion in market value (2016 dollars). Several parks and rides, hundreds of bus stops, and bus routes, and SMART rail track, including the San Rafael Transit Center.

Vulnerable Assets

Sea Level Rise (SLR) Scenarios
- Scenario 5: 60” SLR
- Scenario 6: 62” SLR

Location Indicators:
- Unincorporated
- Municipally
- Road
- Bay

Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County and data providers here in make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future revision. Local site conditions must be examined. Commercial use is prohibited.
A significant degree of uncertainty exists as to how soon these increases in sea level could occur because future carbon emissions are an unknown. However, even if global citizens stabilize carbon emissions, sea level rise would likely continue. Moreover, even if the growing global population reduces carbon emissions to levels where atmospheric concentrations decline, the decline will be slow and sea levels would still likely continue to rise for decades, and hundreds of years could pass before the sea level stabilizes or drops. If emissions continue to increase, the rate of sea level rise is also likely to increase and these assets could be vulnerable sooner than this assessment presents. Because of this uncertainty, this assessment is the first step in an iterative process that will need to be updated as additional science becomes available and adaptation efforts are implemented. The sea level rise preparation process will require consistent monitoring and evaluation to improve modeling assumptions and ensure preparation efforts are effective and efficient.

Hamilton Wetlands and Aramburu Wildlife Preserve were recently enhanced, and wetland restoration is in planning for Bothin Marsh, McInnis Park, and Novato’s baylands. Nonprofits are also working to include: Marin Audubon Society project in Corte Madera, and the Coastal Conservancy’s Bel Marin Keys restoration project once funds are secured.

Combined with potential losses in West Marin due to potential sea level rise, the impacts to Marin County will be significant across all asset categories. The image to the left combines estimates for land area that would be lost at MHHW across the near-term, 2030, the medium-term, 2050, and the long-term, 2100 scenarios applied to Western and Eastern Marin.

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With this vulnerability assessment, Marin County professionals, officials, residents, employees, and other Bay Area communities can gain an understanding of the potential fallout from higher high tides in a no action scenario. With this comprehensive view of the potential issues, Marin County communities can approach preparing for this shared concern with greater efficiency and collaboration.

Tiburon’s Main Street buildings are from the early 1900s, and are adjacent to the ferry terminal. Credit: Marin CDA

Low lying properties in Black Point. Credit: Marin CDA
Introduction

Climate change is affecting natural and built systems around the world, including the California coast. In the past century, average global temperature has increased about 1.4°F, and average global sea level has increased 7 to 8 inches.\(^9\) Sea level at the San Francisco tide gauge has risen 8 inches over the past century, and the National Research Council (NRC) projects that by 2100, sea level in California south of Cape Mendocino may rise 66 inches.\(^10\) The two major causes of global sea level rise are thermal expansion of warming oceans and the melting of land-based glaciers and polar ice caps.\(^11\)

While Marin’s shoreline already experiences regular erosion, flooding, and significant storm events, sea level rise will exacerbate these natural processes, leading to significant social, environmental, and economic impacts. The third National Climate Assessment cites strong evidence that the cost of doing nothing exceeds the costs associated with adapting to sea level rise by 4 to 10 times.\(^12\) Therefore, it is critical the County of Marin, municipalities, and special districts plan and prepare for the impacts of sea level rise to ensure a resilient county for present and future generations.

This publication presents the Bay Waterfront Adaptation and Vulnerability Evaluation (BayWAVE) for Marin’s San Francisco, Richardson’s, and San Pablo Bay communities’ built and natural assets. This effort is part of an ongoing scientific, collaborative, and public process to understand and prepare for sea level rise along the Marin shoreline. This Vulnerability Assessment seeks to provide context and estimates of the physical and fiscal impacts to shoreline over the coming decades. This analysis highlights the complexity of the potential impacts and the need for both concerted and individual actions in the face of rising tides. The data presented can be used to prioritize efforts, seek funding, and shape policy and development discussions.

The County of Marin Department of Public Works is the project lead for the Bay Waterfront Adaptation & Vulnerability Evaluation (BayWAVE) program. The program began in September 2015 with funding from County of Marin and additional financial support from the California State Coastal Conservancy. Several multi-jurisdictional committees guide the BayWAVE process. The Executive Steering Committee consists of County of Marin and local jurisdiction representatives to guide staff and provide direction at critical milestones. The Policy Committee is made up of elected officials from each city and the County of Marin. The Technical Advisory Committee...

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Committee includes staff from local, state, and federal agencies. These committees are essential in achieving the BayWAVE goals to establish an efficient shared learning process and messaging platform, and create a collaborative environment to prepare for sea level rise. See the Acknowledgements for a complete list of committee participants.

This Vulnerability Assessment is advisory and not a regulatory document or legal standard of review for action the County of Marin, municipalities or other involved special governments may take. Such actions are subject to the applicable requirements in each jurisdiction’s governing documents and applicable state and local regulations.

The County of Marin, municipalities, and special jurisdictions participating in this assessment have engaged in sea level rise planning and climate action for several years. For example, Marin’s Countywide Plan (2007) addresses sea level rise in two policies: EH-3.k Anticipate Climate Change Impacts, Including Sea Level Rise and C-EH-22 Sea Level Rise and Marin’s Coast. Other local efforts include sea level rise white papers for San Rafael and Novato, the Here.Now.Us project started by Marin County Supervisor Kate Sears for Southern Marin, the Department of Public Works Richardson’s Bay Shoreline Study, Novato, Southern Marin, and Gallinas Watershed Program’s demonstration projects, and the Collaboration: Sea-level Marin Adaptation Response Team (C-SMART) Program for the West Marin coastline.

This assessment follows extensive efforts throughout the nation, state, and region to understand the science of sea level rise and the impacts it could have. The San Francisco Bay Conservation and Development Commission (BCDC) established the Adapting to Rising Tides program, which includes adaptation planning guidance, and local to regional case studies, and previously published Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on the Shoreline and Innovative Wetland Adaptation Techniques. Most recently, BCDC released a Levee Overtopping Study that determines the water levels required to spill over the tops of levees into the areas the aim to protect. Pacific Gas & Electric (PG&E) also released a climate change vulnerability assessment for the Bay Area. In addition, the California Energy Commission (CEC) released Impacts of Predicted Sea-Level Rise and Extreme Storm Events on the Transportation Infrastructure in the San Francisco Bay Region. Finally, released two years ago with special attention to climate change impacts is the Baylands Ecosystem Habitat Goals Science Update 2015.

In an effort to dovetail with these studies, goals, and regulations, this assessment applies and presents the best available sea level rise and storm surge science to Marin’s shoreline to generate an understanding of Marin’s potential future.

This Assessment examines lands on the Marin County bay shoreline from the Golden Gate Bridge to the Petaluma River (see Map 1). The study area is approximately 85,840 acres and comprises of the entire jurisdiction for each municipality and unincorporated community vulnerable to sea level rise under the BayWAVE scenarios. Communities exposed to sea level rise are:

- **Municipalities**
  - Belvedere
  - Corte Madera
  - Larkspur
  - Mill Valley
  - Novato
  - San Rafael
  - Sausalito
  - Tiburon

- **Unincorporated Jurisdictions**
  - Almonte
  - Bayside Acres
  - Bel Marin Keys
  - Black Point
  - California Park
  - Country Club
  - Greenbrae
  - Kentfield
  - Marin City
  - North Novato
  - Paradise Cay
  - Point San Pedro
  - San Quentin
  - Santa Venetia
  - St. Vincent's
  - Strawberry
  - Tamalpais Valley
  - Unincorporated Tiburon
  - Waldo Point Harbor.
INTRODUCTION

Map 1. BayWAVE Study Area
INTRODUCTION

The locations in the study area most likely to experience sea level rise and storm surge impacts in this century are low lying areas in Marin’s shoreline communities, especially east of US Highway 101. However, the dry unexposed portions of every community in the study, Tamalpais Valley, Strawberry, Da Silva Island, Mill Valley, Belvedere Island, Tiburon uplands, Sausalito, and San Rafael, could be indirectly impacted. Similarly, East Marin communities outside of the study area, such as Fairfax, San Anselmo, Ross, Alto, Lucas Valley, and others could be vulnerable to transportation network and utility impacts. Note that while in Marin County, the Marin Headlands and Fort Baker are Federal property and not the focus of this assessment. The Federal Parks assessment is at http://www.nature.nps.gov/geology/coastal/coastal_assets_report.cfm.

This assessment is organized into five major sections: (1) methods, (2) asset profiles, and (3) municipality profile, and (4) the Conclusion. The methods section details the background science and research methods used in the BayWAVE process. Asset profiles highlight the vulnerable features bayside residents, employees, and visitors depend on, such as buildings, roads, drinking water, septic, and others. The municipality profiles detail all asset vulnerabilities for each exposed municipality. The Unincorporated Marin profile also provides the same analysis for areas within County of Marin jurisdiction. Each profile details key issues and geographic locations. Asset Profiles highlight initial economic, environmental, equity, and management considerations related to sea level rise vulnerability. Each profile can be read independently, enabling asset managers to focus on a professional area, and community members, elected officials, and others to read about their community as a whole. The conclusion summarizes the impacts by time-period or onset of near-, medium-, and long-term impacts across all asset types and communities.

Key findings include:

- Southern Marin would likely suffer the worst flooding impacts, and could experience these impacts in the near-term.
- Increasingly compromised access to and from the Manzanita Interchange of US Highway 101 and 1 could affect hundreds of thousands of residents, employees, and visitors.
- Reductions in useable space for living, tourism, transportation, and natural resources could impact approximately 12,750 properties, more than 12,000 buildings, and 100 miles in roads.
- Based FEMA HAZUS damage estimates, waves, wind, and temporary flooding during storms could account for $60 million to $6 billion (2016 dollars) in building damages.
- Impacts to wastewater treatment in the Sausalito, Tamalpais, Almonte, Alto, Mill Valley, Novato, and Bel Marin Keys could affect tens of thousands of residents.
- Physical and economic impacts will be felt differently across the various income and age groups, causing social and economic inequities.
- In California, tidelands (land below the mean high water mark) and submerged lands are under public trust. As the sea level rises, thousands of private properties, if still in use, could be subject to the Public Trust Doctrine, become Waters of the State, and be required to pay a leasing fee.
- The most vulnerable habitats are shoreline beaches and marshes south of St. Vincent’s.
- Areas that are not exposed to rising bay waters under the BayWAVE scenarios can still be vulnerable to sea level rise when the wastewater treatment plant, ports, and major roadways become compromised under flooding conditions.
- Marin is not self-contained and could feel impacts from across the Bay region, such as the Port of Oakland, which receives imports and exports for the entire Bay Area, or transportation network in San Francisco and the East Bay that,
when flooded, would disrupt commuting, and regional and global travel.

- Sea level rise is one of several climate change impacts residents will likely face. Combined with typical hazards that already exist (e.g. liquefaction and ground shaking near fault lines, erodible soils, and heavy rainfall), Marin is more vulnerable than this assessment can describe.

This assessment is the first step in an ongoing iterative process. The sea level rise preparation process will require consistent monitoring and evaluation to improve modeling assumptions and ensure preparation efforts are effective and efficient. With this vulnerability assessment, Marin County professionals, officials, residents, employees, and other Bay area communities can gain an understanding of the potential fallout from higher high tides in a no action scenario. With this comprehensive view of the potential issues, Marin County communities can approach preparing for this shared concern with greater efficiency and collaboration.

### Marin Flood History


**February 10th 1925** More than seven inches of rain fell in the Ross Valley, overflowing creeks, and flooding streets. Extensive damage occurred to homes and infrastructure in San Anselmo, Ross and Kentfield.14

**1956-58** Corte Madera Creek experienced major flooding that prompted a large Army Corps of Engineers flood control project. Due to continuous flooding, the Kentfield Fire Department tied a rowboat to the Laurel/Sir Francis Drake sign for use.15

**January 1982** The ‘Great Storm of 1982,’ dumped sixteen inches of rain that killed four residents, destroyed 35 Marin homes, and damaged 2,900 more, totaling $80 million in damages.16,17

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15 Source Unknown


METHODS

Methodology

The BayWAVE Vulnerability Assessment process (see Figure 1) is guided by CalAdapt through the following phases of analysis:

- **Phase 1: Exposure**: Assess potential changes in water level from sea level rise, storm events, and geomorphic change to determine the built and natural assets that could be exposed to saltwater.
- **Phase 2: Sensitivity**: Assess the degree of damage or disruption tidal and storm surge flooding could cause on the exposed assets.
- **Phase 3: Adaptive Capacity**: Assess each asset’s adaptive capacity, or ability to respond successfully, to flooding, without human intervention.
- **Phase 4: Potential Impacts**: Evaluate the potential consequences to the assets and larger context, assuming no intervention actions.
- **Phase 5: Risk & Onset**: Describe the certainty and timing of impacts.

**Modeling Methods**

Sea level rise estimates used in this analysis are from the USGS Coastal Storm Modeling Systems (CoSMoS) and are viewable online through the Our Coast Our Future (OCOF) Flood Map tool. OCOF was developed through a partnership of several notable institutions and agencies, and represents the best available sea level rise and storm science.

OCOF uses the USGS’s Digital Elevation Model (DEM) constructed for the region with 2-meter horizontal grid resolution based on North American Vertical Datum of 1988 (NAVD88) elevations, and USGS’s numerical modeling system called Coastal Storm Modeling System (CoSMoS) to produce a combination of 40 different sea level rise and storms scenarios. CoSMoS scales down global and regional climate and wave models to produce local hazard projections.

High quality elevation data incorporated in the DEM was used to create maps of mean higher high water (MHHW) tidal elevation, and provides the option to add storm surges of different magnitudes. Mean higher high water is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. Each day has two high tides, one typically higher than the other. The higher values are used for this analysis. Some days the higher high tide will be lower or higher than other days, however, several days of flooding a month, several months a year, or even once every year would be problematic depending on the resource being examined.

Note, also because the analysis uses high tide, properties near the inland extent of properties exposed to MHHW may not flood at low tides. On

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20 National Tidal Datum Epoch is the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal data.

METHODS

the other hand, these properties, and properties just beyond the inland extent of scenario 6, the most severe scenario examined in this report, could experience flooding from the highest high tides, especially in combination with storms and/or king tides.

Figure 2. Tidal Datum Comparing MHHW to Mean Sea Level and Low Water Levels

CoSMoS accounts for wave run-up and set-up, storm surge of the ocean, seasonal effects, tides, levees, river discharge, and wind from the San Francisco Bay. Note that this tool only accounts for bay water levels and does not assess fresh stormwater flooding upstream or changes in the shoreline (geomorphology) as erosion continues. Thus, storms used in this analysis include bay storm surge only, not additional freshwater creek flooding upstream. In addition, this analysis does not account for the ability of pump stations to drain flooded areas.

Table 1 shows the range of sea level rise projections for California adopted by the National Research Council in 2012. Given the uncertainty in the magnitude and timing of future sea level rise, this analysis uses a scenario based approach to assess a range of potential sea level rise and storm surge exposure. The six USGS CoSMoS scenarios selected for the BayWAVE Vulnerability Assessment in Table 2 align with the NRC 2012 estimates as follows:

- Scenarios 1 and 2 represent the near-term projection anticipated by 2030.
- Scenarios 3 and 4 represent the medium-term projection anticipated by 2050.
- Scenarios 5 and 6 represent the long-term projection anticipated by 2100.

Table 1. Sea Level Rise Projections for San Francisco, CA Region

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Projected Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>by 2030</td>
<td>1.6 – 11.8 inches</td>
</tr>
<tr>
<td>by 2050</td>
<td>4.7 – 24 inches</td>
</tr>
<tr>
<td>by 2100</td>
<td>16.6 – 65.8 inches</td>
</tr>
</tbody>
</table>

Source: NRC 2012

Table 2. BayWAVE Sea Level Rise & Storms Scenarios

<table>
<thead>
<tr>
<th>Sea Level Rise Scenario</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 10 inches</td>
<td>Near</td>
</tr>
<tr>
<td>2 10 inches+100-year storm</td>
<td>Medium</td>
</tr>
<tr>
<td>3 20 inches</td>
<td></td>
</tr>
<tr>
<td>4 20 inches+100-year storm</td>
<td>Long</td>
</tr>
<tr>
<td>5 60 inches</td>
<td></td>
</tr>
<tr>
<td>6 60 inches+100-year storm</td>
<td></td>
</tr>
</tbody>
</table>

Source: marincounty.org
Figure 3 presents another view of the BayWAVE scenarios where the red lengths represent tidal flooding in sea level rise scenarios 1, 3, and 5, and the blue lengths represent the additional storm surge water level associated with scenarios 2, 4, and 6. Together these bands show the potential flooding in the near-, medium-, and long-terms.

The odd numbered scenarios illustrate sea level rise only. Even numbered scenarios illustrate sea levels and incorporate the storm flooding from a future based 100-year storm surge. The scenarios include storm surges because storm surges have the potential to cause catastrophic damage. The CoSMoS model uses research and predictions for future storm patterns to create the future storm typology used in the BayWAVE scenarios. Future storms are anticipated to come from a southerly direction, as opposed to historic storms, which tend to come from the north. For more information on how storms were modeled see references on the OCOF website.

A 100-year storm surge has one percent chance of happening in any storm in a given year. Within a 30-year mortgage, a 100-year storm has a nearly 30 percent chance of occurring. Note that, as climate change continues, the 100-year storm surge level of flooding may occur more frequently, increasing the annual risk of this level storm occurring from a 100-year storm surge to a 50-year storm surge, for example. In addition, there are more frequent storm surges, and less frequent storm surges such as the, 200-year, 400-year, annual, or 5-year storm surges. Less frequent larger storms would result in more severe flooding than presented in this report, whereas, smaller storm surges would produce less severe flooding.

Maps 2 and 3, on the following pages, show the furthest inland extent of scenario 6. Maps 4 and 5 show scenarios 1, 3, and 5, and Maps 6 and 7 show scenarios 2, 4, and 6. The shoreline is typically mapped in two maps: (1) the northern study area, north of Pt. San Pedro, and (2) the southern study area, south of Pt. San Pedro, halves of the study area. The call out circle maps show zoomed in images of locations that may be difficult to see. The circles do not indicate these do not indicate that there areas are more vulnerable than areas not depicted in the circular maps.

Map 3. Southern Study Area Inland Extent of Scenario 6

Inland Extent: Sea Level @ 60"+100-year Storm

Location Indicators
- Unincorporated
- Municipality
- Road
- Bay

Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County, and data providers here in, make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future revision. Local site conditions must be examined. Commercial use is prohibited.

1: Downtown San Rafael
2: Greenbrae/Larkspur
3: Corte Madera
4: Belvedere/Tiburon
5: Mill Valley
6: Waldo Pt. Harbor
Map 5. Southern Study Area Sea Level Rise Scenarios

BayWAVE Sea Level Rise (SLR) Scenarios
- Red: Scen 1: 10" SLR
- Yellow: Scen 3: 20" SLR
- Blue: Scen 5: 60" SLR

Location Indicators:
- Unincorporated
- Municipality
- Road
- Bay

1: Canal Neighborhood
2: Greenbrae Boardwalk/Larkspur/Corte Madera
3: Corte Madera
4: Belvedere/Tiburon
5: Almonte/Mill Valley
6: Marinship

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Map 6. Northern Study Area Sea Level Rise and 100-year Storm Surge Scenarios

BayWAVE Sea Level Rise (SLR) & 100-year Storm Surge Scenarios

- Scen 2: 10” SLR + Storm Surge
- Scen 4: 20” SLR + Storm Surge
- Scen 6: 60” SLR + Storm Surge

Location Indicators

- Unincorporated
- Municipality
- Road
- Bay

1: Black Point/Green Point
2: U.S. Hwy. 101 @ Rowland Blvd.
3: Bel Marin Keys
4: Hamilton
5: Santa Venetia/ Marin Lagoon
6: Buck's Landing

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Map 7. Southern Study Area Sea Level Rise and 100-year Storm Surge Scenarios

BayWAVE Sea Level Rise (SLR) & 100-year Storm Surge Scenarios

- Scen 2: 10"SLR+Storm Surge
- Scen 4: 20"SLR+Storm Surge
- Scen 6: 60"SLR+Storm Surge

Location Indicators
- Unincorporated
- Municipality
- Road
- Bay

1: Canal Neighborhood
2: Greenbrae Boardwalk/Larkspur/Corte Madera
3: Corte Madera
4: Belvedere/Tiburon
5: Almonte/Mill Valley
6: Marinship

Disclaimer: Vulnerability Assessment maps, tables, etc. can be used as a resource to help identify potential hazardous areas and vulnerable assets. Marin County and data providers here in make no warranties of the accuracy or completeness of maps and data. Maps are representational and subject to future revision. Local site conditions must be examined. Commercial use is prohibited.
According to the San Francisco Bay Conservation and Development Commission’s *A Sea Level Rise Strategy for the San Francisco Bay Region* noted that it is particularly difficult to develop a strategy for dealing with sea level rise when the temperature increase scenarios yield a tenfold difference between the lowest and highest potential increases in the San Francisco Bay water level over the next 100 years.23

This high degree of uncertainty, due differing assumptions in carbon emissions, in sea level rise modeling results in a range of onset predictions. Variances between the predictions increase further out in time. This uncertainty is heightened by the non-linear growth rate of sea level rise.24,25 Because of this variation, the BayWAVE scenarios do not focus on years, rather a framework of near-, medium-, and long-term scenarios. The OCOF tool enables the user to view the year a sea level projection could be met across the various published sea level estimates on the OCOF website.

Regardless, even if the world stabilizes carbon emissions, sea level rise will continue. Even if the global population reduces carbon emissions to levels where atmospheric concentrations decline, the decline will be slow, sea levels could continue to rise for decades, and hundreds of years could pass before sea level stabilizes or drops.26,27

**Known Issues**

The USGS acknowledges local modeling issues at the Petaluma River where dense vegetation leads to a false elevation reading and thus, under-predicts the potential flooding extent. Maximum flood potential indicates more probable flooding extents in these locations. In addition, the 100-year storm scenario flooding extents in the vicinity of Petaluma River and Novato may be under-predicted. The modeling team manually adjusted parameters to show more probable flooding behavior. Local professionals also suspect that water absorbed by the marshes at China Camp State Park may yield less flooding than the model estimates.

In addition, several sites underwent, or are currently undergoing, elevation increases after the baseline imagery was taken in 2010. Thus, the model and maps may overestimate flooding. These projects are shown on Maps 8 and 9 and include:

- Waldo Point Harbor: Filled and elevated parking and entrance area.
- Rose Garden Neighborhood, Larkspur: This recently completed development was elevated to meet FEMA and County flood prevention requirements.
- Aramburu Island, Strawberry: This man-made barrier island off Harbor Point in Strawberry was improved in 2012 and offers enhanced protection from wave impacts during storms.
- Hospice and base of Cal Park Hill: Recent construction may have elevated the site above 2010 elevations. This could result is less than flooding than estimated in this assessment.
- The Strand and Loch Lomond Marina, San Rafael: This project is near completion. The sites were filled with sediment and elevated to meet FEMA standards.
- Redwood Landfill: Roughly two feet in height was added to the external and internal levees after 2010.

Another issue arises with the Belvedere and Bel Marin Keys Lagoons. These lagoons are managed with tide gates that can close during high tides. The model treats these gates as open. So long as the tide gates and levees are not over topped, closing these protective devices could reduce flooding to properties on the lagoons in the near- and medium-terms.

Finally, note that the model does not take planned projects into consideration and assumes no action taken to prepare of adapt for sea level rise. Several projects along the shoreline are planned that could also help to reduce sea level rise flooding threats. These projects will be presented in the BayWAVE sea level rise early action report, the counterpart to this Assessment.
Map 8. Northern Study Area Known Issues with CoSMoS Model
Map 9. Southern Study Area Known Issues with CoSMoS Model
Sea Level Rise Maps & FEMA

Several shoreline communities already grapple with stormwater and storm surge flooding on a near yearly basis and qualify for federal flooding insurance under the Federal Emergency Management Agency (FEMA). FEMA maps flood prone area in maps called Flood Insurance Rate Maps (FIRMs). These maps, while related to flooding, do not consider future potential sea level rise flooding. As the sea level rises, FIRMs would need to be updated to represent the new existing conditions. Other major differences between FIRMs and the sea level rise maps in this assessment are:

- FIRMs are based on historic and current trends and assumptions. CoSMoS sea level rise maps are based on modeling of potential future conditions.
- FIRMS address bay surge and stormwater creek flooding. CoSMoS does not address stormwater creek flooding, and
- FIRMS can incorporate policy decisions to exclude the role of non-FEMA certified protective shoreline armoring. CoSMoS is based solely on elevation, such that any shoreline armoring that contributes to elevation is accounted for.

Assessment Methods

As described in CalAdapt, vulnerability is based on an asset’s exposure, sensitivity, and adaptive capacity to rising tides and bay surge threats. Such that, if an exposed asset is moderately or highly sensitive to sea level rise impacts, with low to no adaptive capacity, the asset is vulnerable.

Assets were identified using existing MarinMap geographic data layers for roads, trails, parks, public facilities, utility districts, buildings, and parcels, and Department of Fish and Wildlife sources for wildlife species, habitats, fishing piers, marinas, access points, and ports. The Technical Advisory Committee supplemented these data sources with additional assets. Note that not all vulnerable assets are mapped due to data conflicts or unavailable geographic data. This does not imply that an asset is not vulnerable. This is especially true for utility assets. The data layers generated span several years, and changes to the built environment may have occurred since the data was last updated. Where identified, these areas were manually adjusted to reflect known current conditions. For example, based on aerial imagery, Niel Cumings Elementary school appears to be one large building, however, upon site visit, it becomes clear the site has four buildings connected by awnings. Improving the data comprehensively was not within the scope of this analysis, thus buildings numbers may be slightly off in some locations.

Phase 1: Exposure

To determine what could be exposed to sea level rise at MHHW and/or a100-year storm surge, the six BayWAVE scenarios, identified asset locations, and aerial imagery were overlaid in ArcGIS, a geographic statistical computer program. Assets intersecting sea level rise and storm scenarios were identified as exposed, and further assessed for sensitivity and adaptive capacity to determine if the asset is vulnerable to:

- Extreme event flooding during the annual highest high tides and/or storm surges that cause nuisance flooding,
- Inundation at, at least, one high tide a day, several days a month, that results in chronic flooding,
- Erosion and geomorphic evolution from higher high tides and extreme storm events,
- Wave run up and high winds in extreme storm events,
- Saltwater intrusion,
- Rising water table, and/or
- Habitat shifts (applicable to natural resources).

In addition to geographic extent, CoSMoS GIS layers illustrating potential flood depth at MHHW were spatially joined with each vulnerable asset yielding average depths for scenarios 1, 3, and 5. Flood depth was calculated by converting GIS vector data to raster data to break the flood depth layer into thousands of cells, each with an assigned flood value. For roads, a high and low value was calculated on the line segment. Bridges are not quantitatively accounted for in this assessment. For buildings, cells underlying the building footprint were averaged to one flood depth at MHHW for scenarios 1, 3, and 5 for each building. Note that flood depth data is not available for all vulnerable areas and assets, especially those that exist in the bay beyond mean sea level and already subject to tidal influences. The data presented in this Assessment is...
METHODS

for what is available and may not directly compare with data presented under exposure.

Flood depth figures are displayed in the onset and depth tables in each profile. In these tables, roads were assigned high and low values along the exposed segments for each scenario. Exposed road mileage provided is road miles, not lane miles. Lane mileage would more than double the mileage figures presented in this assessment. Where buildings are presented as a neighborhood group, a maximum average flood depth is provided. Where data is available, additional analysis summarizes how many buildings in each community could flood by one-foot flood depth intervals for scenarios 1, 3, and 5.

Phases 2 & 3: Sensitivity & Adaptive Capacity
The project team interviewed more than 100 asset managers, such as fire chiefs, city planners, transportation agency staff, using the Asset Vulnerability Assessment Tool, available in Appendix A, to assess built and natural resource assets. The tool is designed based on previous pre- and post- disaster assessments conducted in the Bay Area, Southern California, New Orleans, New York City, and guidance from State of California and the US EPA. 

Several public agency professionals were interviewed due to a high number of public assets in the exposed areas. Homeowners’ association representatives were invited to be interviewed; however, home owners or non-public property owners were not individually interviewed. A list of interviews can be found in Appendix A.

Asset managers were interviewed in person or by phone to answer two primary questions:

1. How sensitive is the asset to each exposure or threat? 
2. And if sensitive, what is the adaptive capacity, or the asset’s ability to maintain its function without further intervention (human action)?

Any asset deemed moderately or highly sensitive to flooding or storm damage, with low to no adaptive capacity is considered vulnerable. Other questions about previous disruptions and the nature of potential disruptions were discussed to provide context to the qualitative statements. The interview results were combined with geographic data to develop this Vulnerability Assessment.

Additional analysis was conducted to determine the potential monetary losses from storm damages to buildings in scenario 6. Scenario 6 is chosen because it is the worst case scenario selected for assessment. This method applies damage levels to all vulnerable buildings in scenario 6 based on the FEMA HAZUS model intervals for yellow, minor damage of $5,000-17,000; orange, damage of $17,001+; and red, destroyed, post-disaster inspection tags. Information on the real estate website Zillow was used to estimate median market value of single-family homes in February 2016.

41 2016 dollars
METHODS

The vulnerabilities found in the assessment process are summarized in Asset, Municipal, and Unincorporated Marin Profiles.

Phase 4: Risk & Onset
Risk & onset assess when and how likely impacts will occur to prioritize actions, though this alone may not be adequate criteria for decision-making. Onset is determined by the scenario an asset is exposed under. The scenario indicates a “no later than” timeline, as opposed to a “not until after” timeline, thus onset could occur before the snapshot in time represented by each scenario. Because of this, this assessment uses near-, medium-, and long-term labeling corresponding with the NRC ranges for before 2030, 2050, and 2100 respectively in Table 1.

All vulnerable assets are at risk of flooding and/or increasing rates of subsidence. Two types of flooding could occur, tidal flooding at MHHW or seasonal storm flooding. All assets that experience tidal flooding will also experience storm surge flooding. Tidal flooding at the average higher high tide could flood an asset once a day, several days a month. Each day has two high tides, thus it is possible that some properties could flood twice a day. Land that is flooded at this frequency is not useable for land based development. Storms surge flooding analyzed in this assessment is a 100-year storm surge, such that this storm surge has a 1 percent chance of occurring each year.

Other Considerations Methods
As adaptation planning moves forward, more detailed study and assessment across each of the 3 E’s: economy, environment, and equity, will be critical. Moreover, the California Coastal Commission’s Sea Level Rise Policy Guidance calls for assessing these, legal consequences, and the cumulative and secondary consequences of the vulnerabilities. The “Other Considerations” section in each asset profile begins to identify issues and opportunities for each “E,” and management. These sections are informed through literature review, asset manager interviews, and policy discussions with professional staff.

Economic: Highlights costs of damage, or preparation, and the cost burden to residents. Potential economic issues and opportunities were determined using several geographic and tabular data sources maintained by the County of Marin, US Census, and Zillow. Note that population and monetary figures are based on current or historic values. Generally, both populations and property values are projected to grow, thus, this assessment underestimates the number of people and value of property that would be vulnerable in the future.

Environmental: Highlights how disruption to buildings, roads, septic systems, and other assets could have secondary impacts on the environment and wildlife. Environmental impacts were gathered from asset managers and literature review.

Equity: Highlights the disparity in cost burden across populations of different social and economic means, and how the social fabric of communities may shift. Several storms impacting the south (i.e. Hurricane Katrina, Hurricane Audrey) have “shown that natural disasters can cause the greatest harm to low-income communities and communities of color.” Populations that may be at higher risk include, low-income, limited English speaking, children, and those with limited mobility or sensory abilities.

Management: Highlights political and management issues that will need to be considered when planning for sea level rise to ensure the public health, safety, and welfare of East Marin residents.

To gain a better idea of these secondary consequences, asset managers were asked several questions about the nature of the damage or disruption that could happen, levels of risk, persons impacted, and if environmental, economic, equity, or political issues could arise. Potential secondary impacts include:

44 Delaware Coastal Programs, Sea Level Rise Adaptation. http://www.dnrec.delaware.gov/coastal/Pages/SeaLevelRiseAdaptation.aspx
METHODS

- Contaminant releases from industrial sites or storage tanks,
- Loss of habitat from increased erosion,
- Loss of jobs and revenue streams,
- Loss of community or sense of place,
- Increased need for government services or intervention, and
- Potential injury and loss of life.

Though the methods for this countywide assessment are robust, some areas may be represented as more vulnerable or less vulnerable than available information suggests. Some locations can only be represented accurately with onsite inspections of ground-level conditions. For example, the homes on Greenbrae Boardwalk, in unincorporated Marin and on Boardwalk One, in the City of Larkspur are raised on piers above tidal marshes. Utilities run to homes above the marsh plain along raised, wooden boardwalks. These communities already live with water and are accustomed to high tides surrounding their homes. In theory, these buildings and associated utilities can be adapted with minimal expense compared to on-land buildings (although they would still be impacted by the flooding in surrounding neighborhoods and streets).

Understanding the full vulnerability of these communities requires, at a minimum, onsite inspections of utilities and base floor elevations for each home; analysis that is beyond the scope of this report. The report uses the best available GIS data to analyze vulnerability. The data does not account for raised floor elevations. The County is committed to regularly updating its assessments in response to new sea level rise projections and the availability of new and better data.

Collectively these methods determine what is vulnerable to sea level rise on the Marin shoreline and at what levels of sea level rise impacts could be felt by. This analysis can be a useful in assessing asset and community sea level rise vulnerabilities, and developing adaptation strategies and policies well suited for this unique and valuable bay region.