**Risk assessment of tunnelling-induced hydrogeological interference on springs using a machine learning approach**

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# Electronic Supplementary Materials

# Hydrogeology Journal

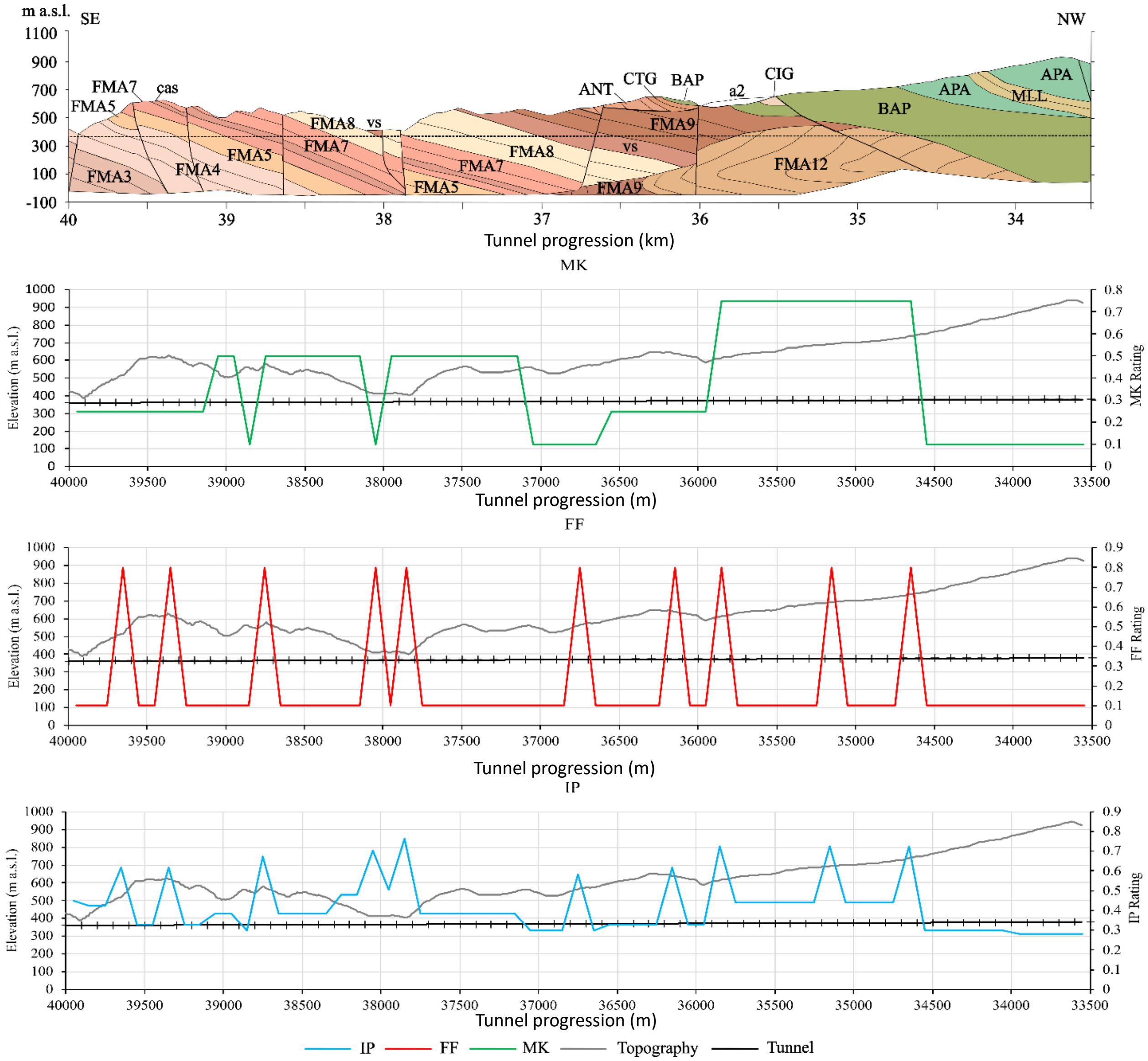


Figure 1: Three hazard parameters from the DHI method applied to the Raticosa tunnel (Canuti et al., 2009). The rock mass permeability (MK, green), fracture frequency (FF, red), and inflow potential (IP, blue) were calculated on 100 m sectors. Geology: FMA: Marnoso-arenacea Formation; FMA3: Premilcuore member; FMA4: Galeata member; FMA5: Collina member; FMA7: Bassana member; FMA8: Nespoli member; FMA9: Civitella member; FMA12: Castel del Rio member; BAP: Polygenic argillaceous breccias; APA: Palombini Formation; MLL: Monte Morello Formation; CTG: Contignano Formation; ANT: Antognola Marls Formation; cas: Casaglia chaotic Unit; a2: Inactive landslides.

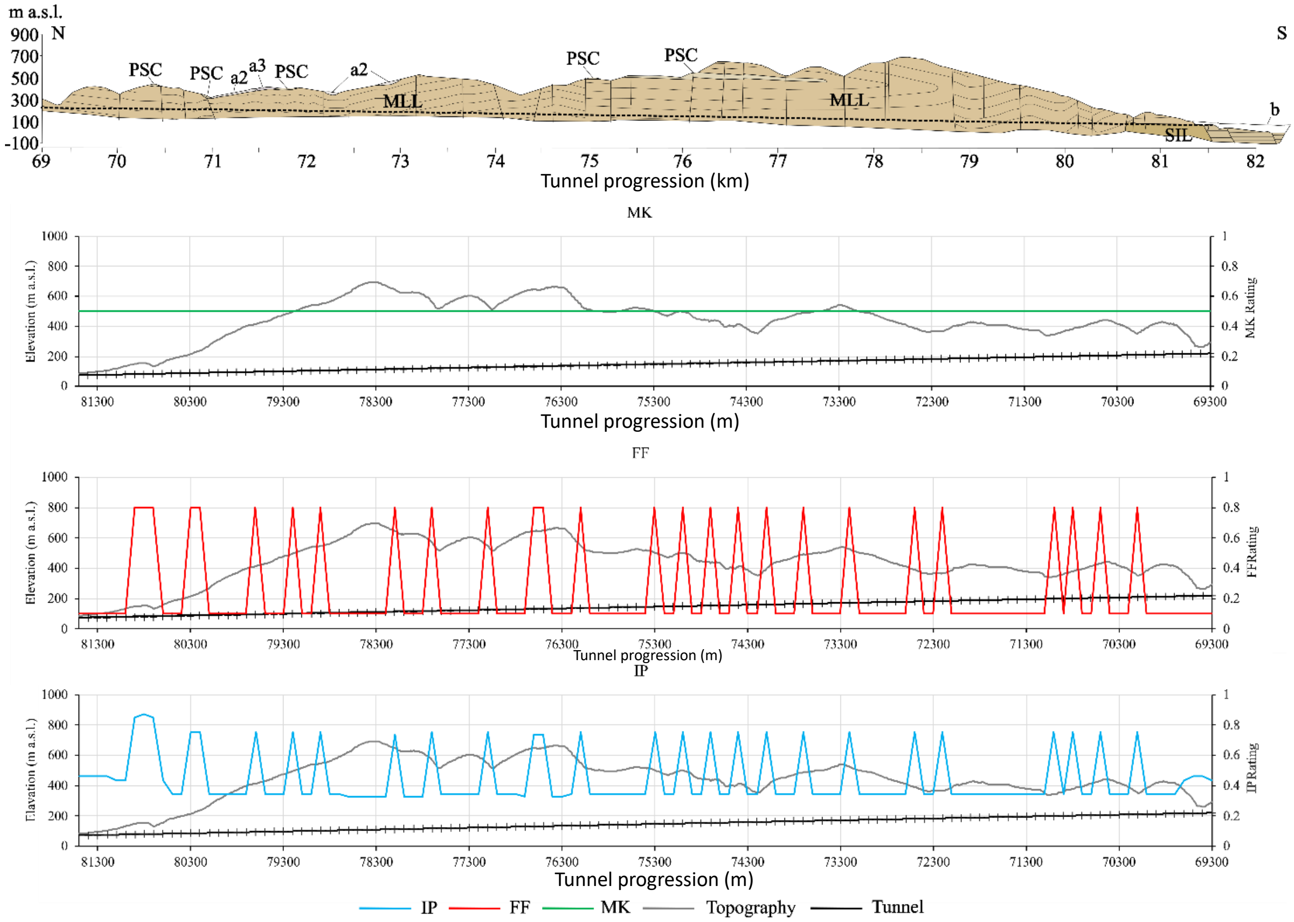


Figure 2: Three hazard parameters from the DHI method applied to the Vaglia tunnel (Canuti et al., 2009). The rock mass permeability (MK, green), fracture frequency (FF, red), and inflow potential (IP, blue) were calculated on 100 m sectors. Geology: MLL: Monte Morello Formation; PSC: Pescina Shale Formation; SIL: Sillano Formation; a2: Inactive landslides; a3: colluvial deposits.

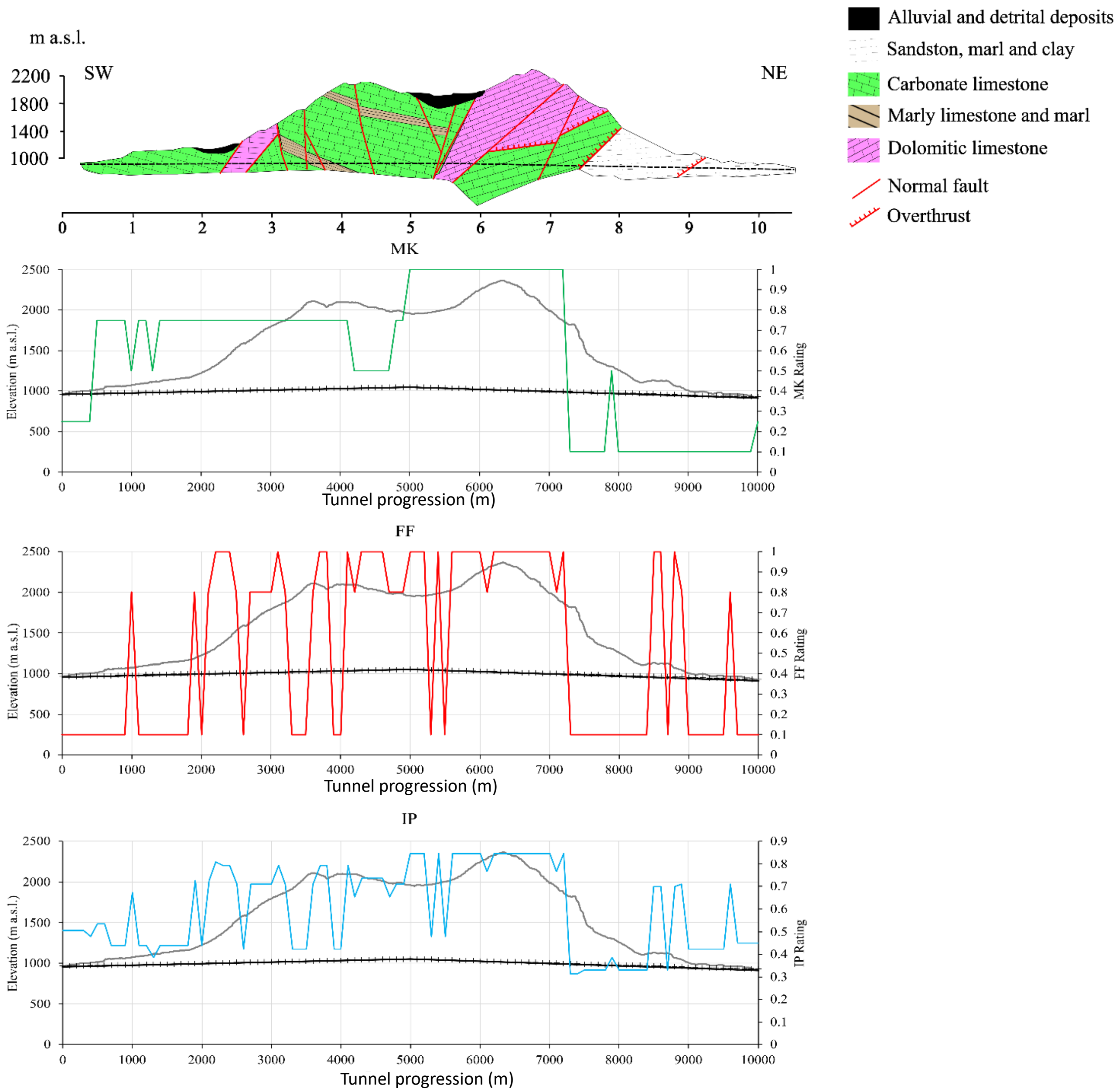


Figure 3: Three hazard parameters from the DHI method applied to the Gran Sasso tunnel (Celico et al., 2005). The rock mass permeability (MK, green), fracture frequency (FF, red), and inflow potential (IP, blue) were calculated on 100 m sectors.

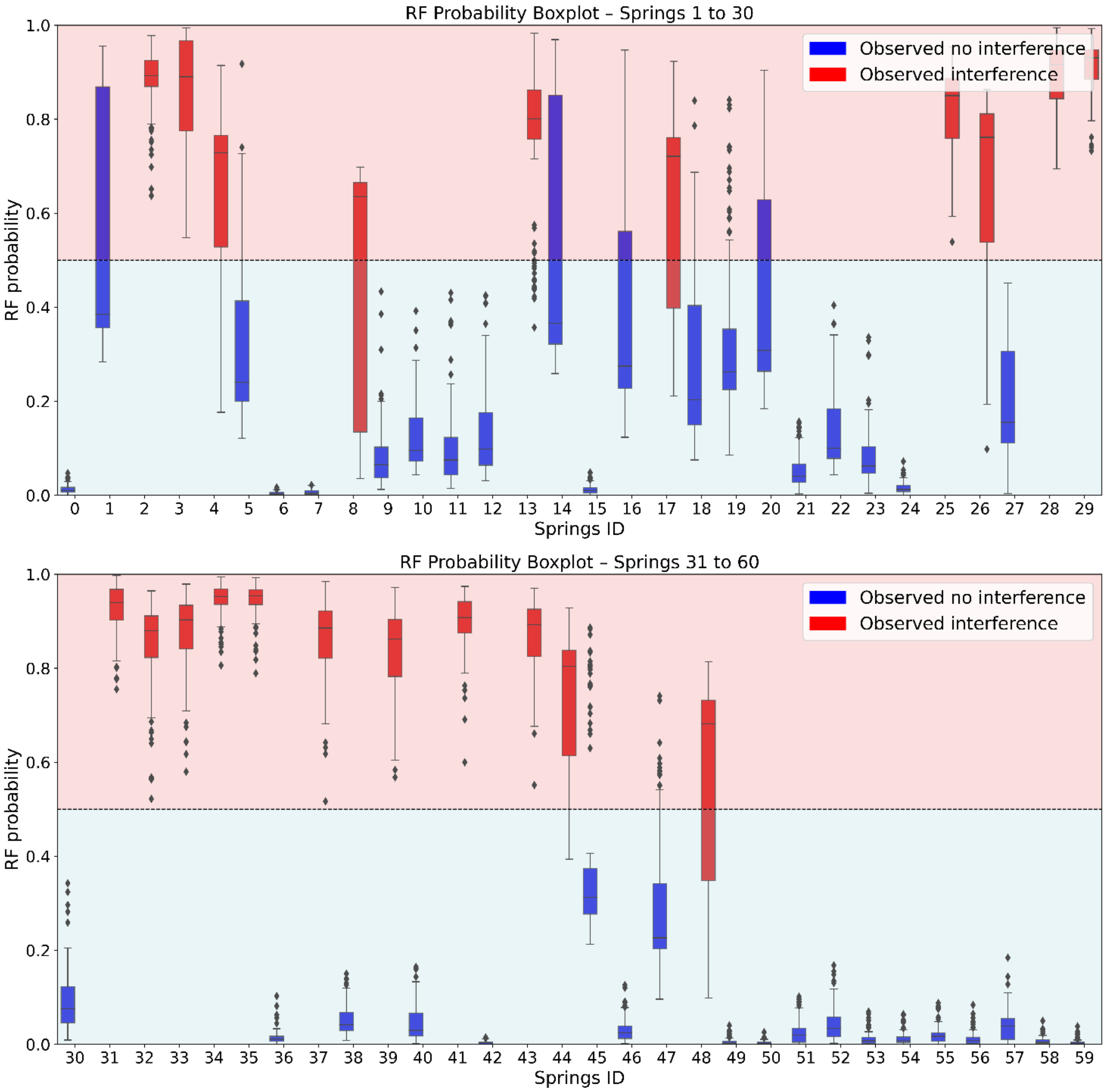


Figure 4: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence case study. From spring 1 to spring 60.

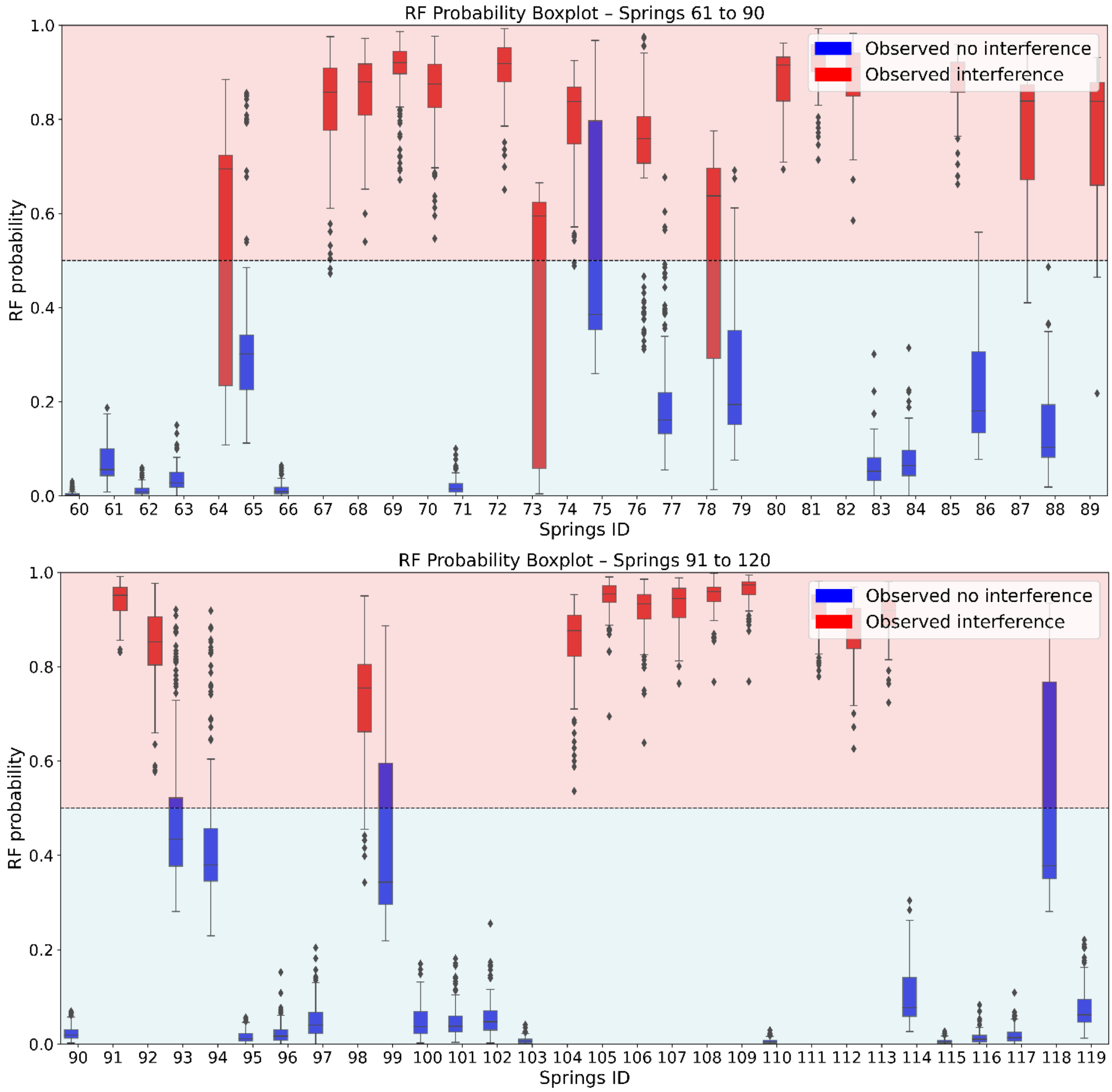


Figure 5: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence case study. From spring 61 to spring 120.

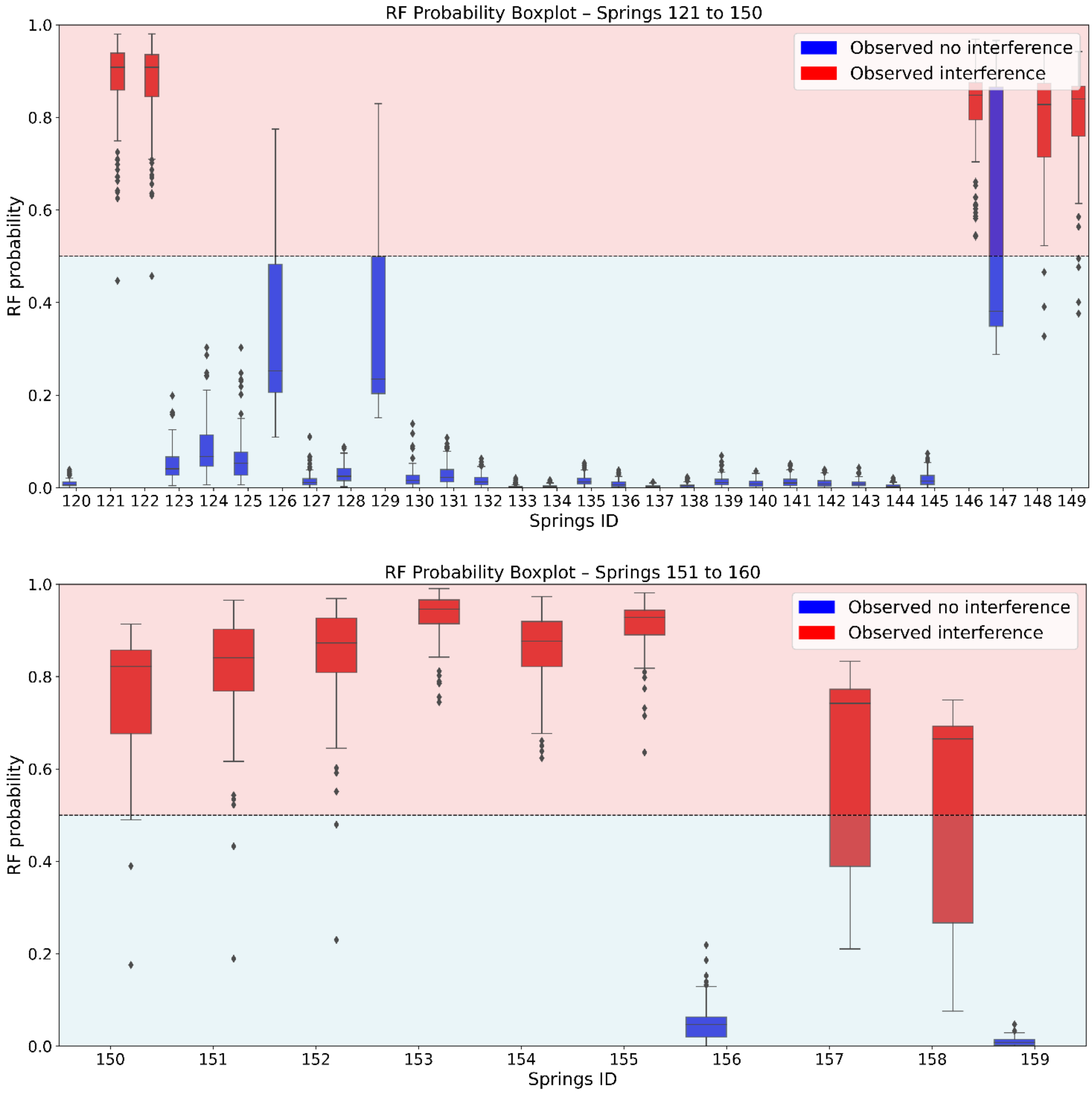


Figure 6: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence case study. From spring 121 to spring 160.

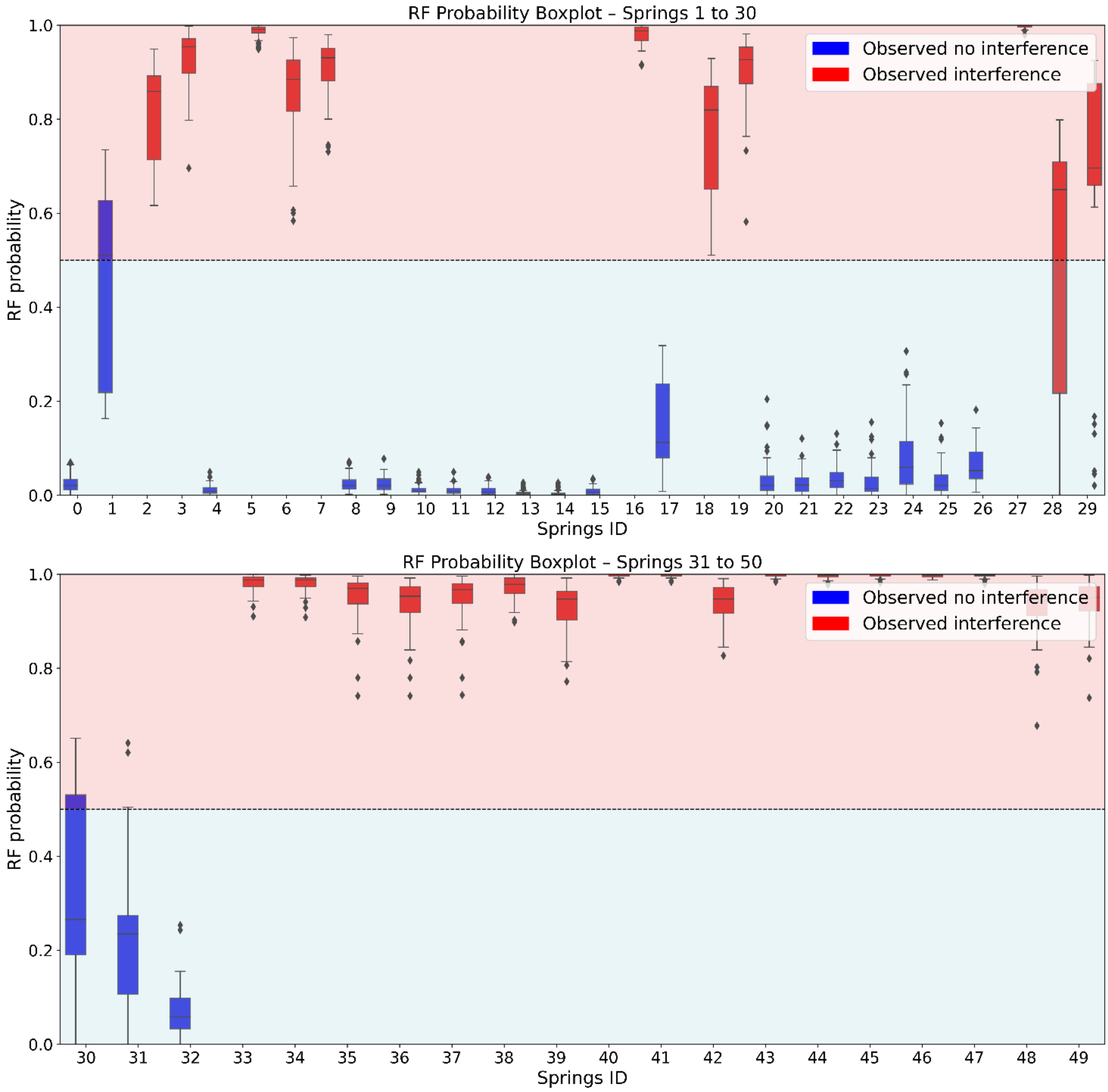


Figure 7: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Gran Sasso case study. All the 50 springs.

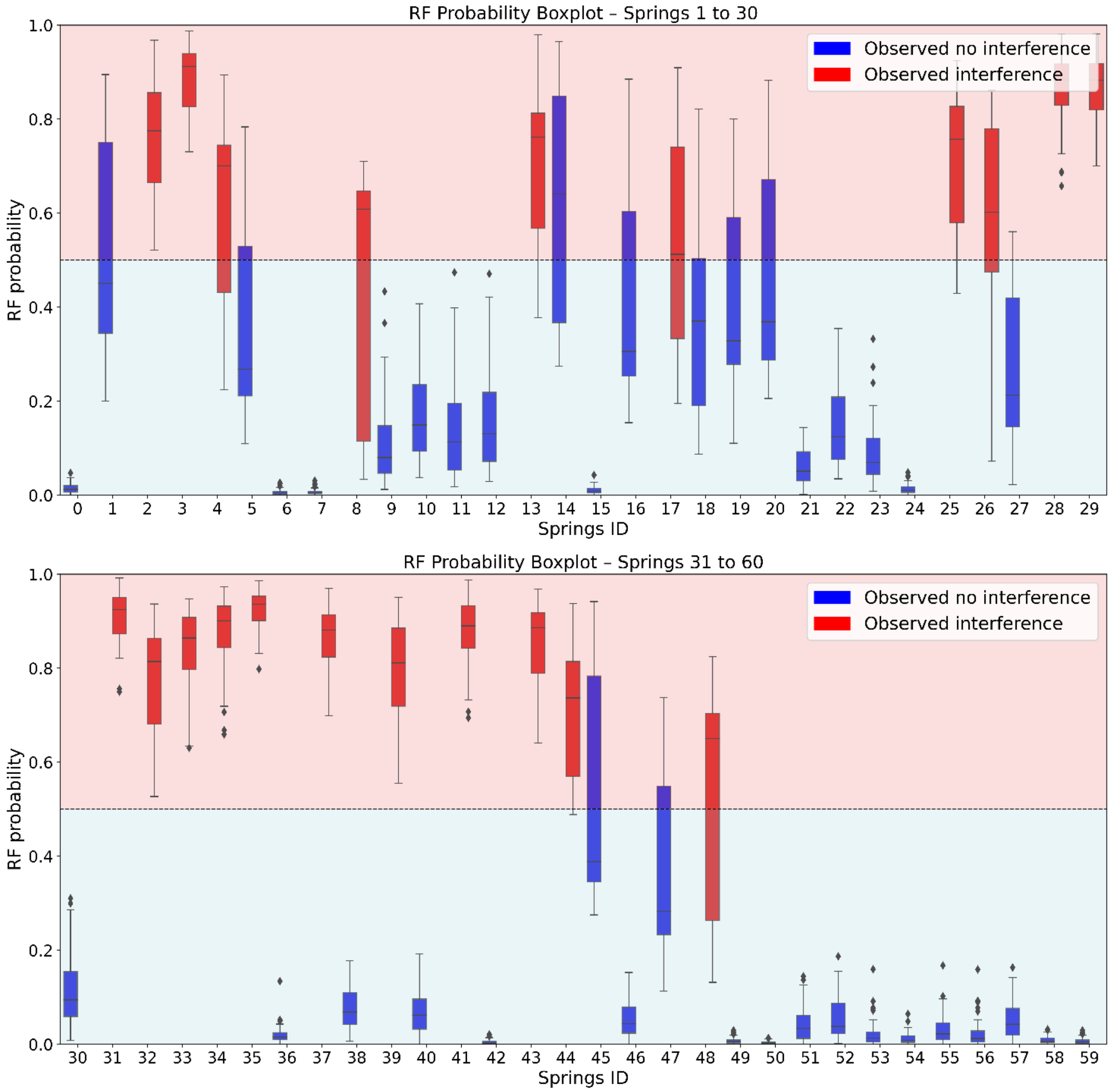


Figure 8: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 1 to spring 60.

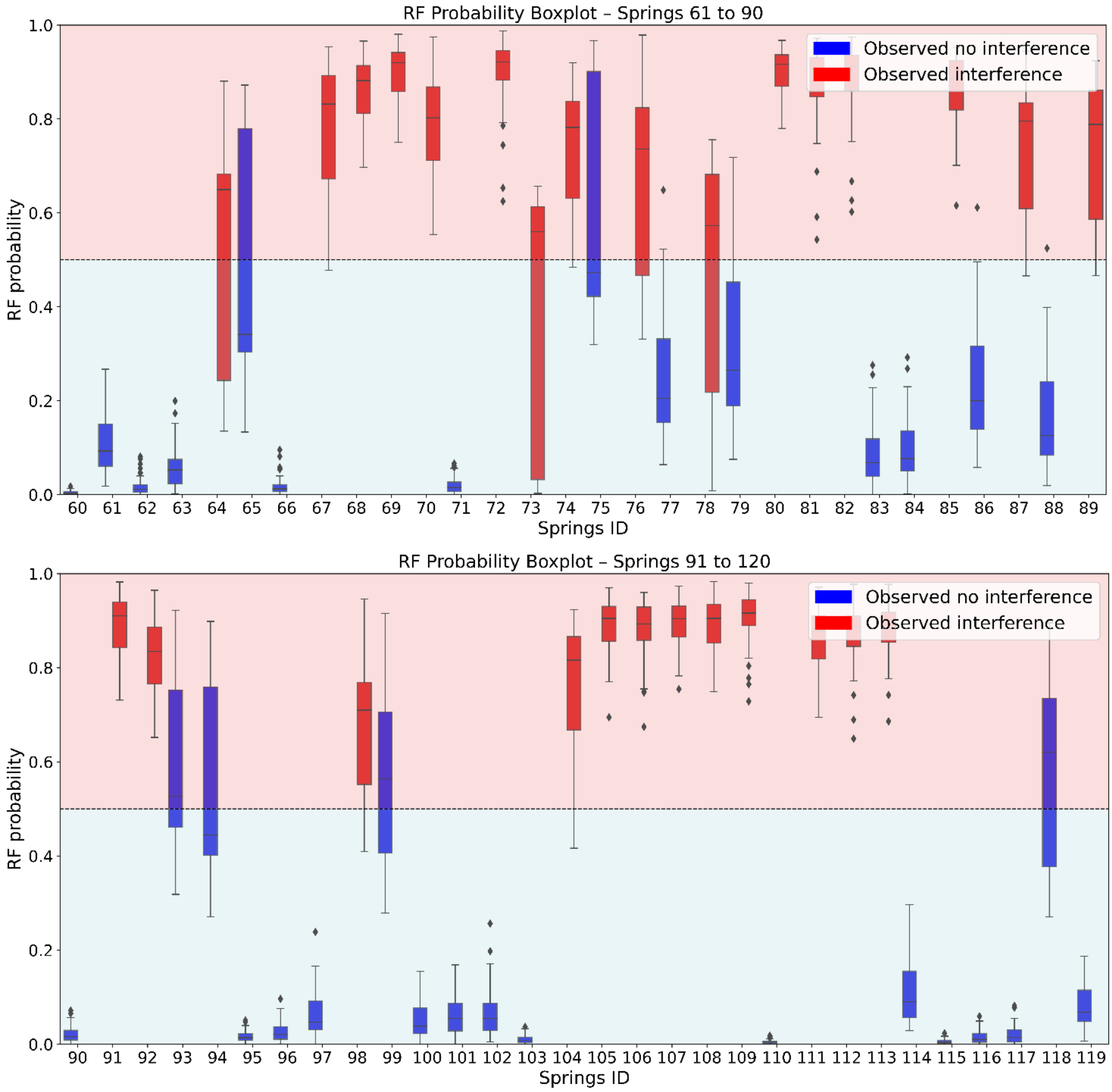


Figure 9: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 61 to spring 120.

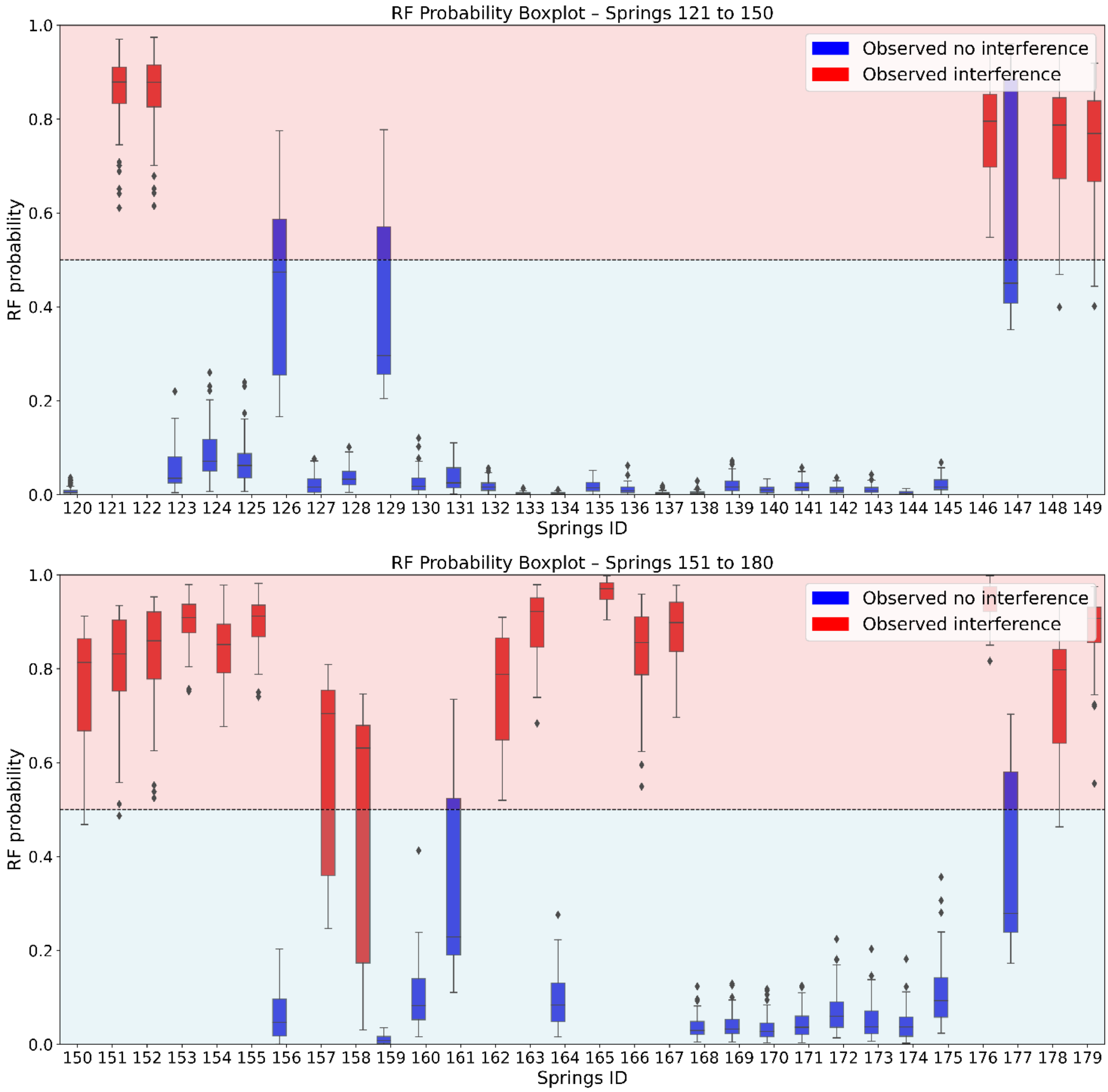


Figure 10: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 121 to spring 180.

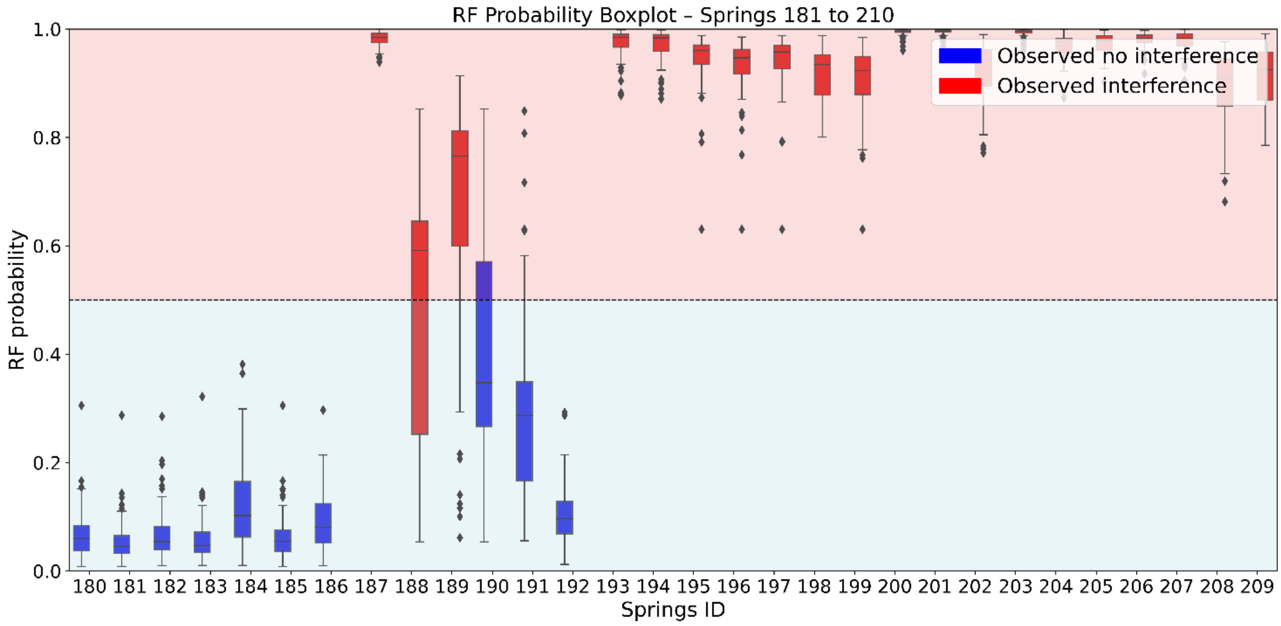


Figure 11: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 181 to spring 210.

| Index | Very low | Low | Medium | High | Risk Class | Impact |
|---|---|---|---|---|---|---|
| 0 | 0 | 76 | 20 | 4 | Low | 0 |
| 1 | 100 | 0 | 0 | 0 | Very low | 0 |
| 2 | 0 | 0 | 11 | 89 | High | 1 |
| 3 | 0 | 0 | 36 | 64 | High | 1 |
| 4 | 0 | 11 | 56 | 33 | Medium | 1 |
| 5 | 10 | 64 | 26 | 0 | Low | 0 |
| 6 | 100 | 0 | 0 | 0 | Very low | 0 |
| 7 | 100 | 0 | 0 | 0 | Very low | 0 |
| 8 | 100 | 0 | 0 | 0 | Very low | 0 |
| 9 | 25 | 3 | 72 | 0 | Medium | 1 |
| 10 | 0 | 11 | 47 | 42 | Medium | 1 |
| 11 | 86 | 13 | 1 | 0 | Very low | 0 |
| 12 | 0 | 71 | 5 | 24 | Low | 0 |
| 13 | 68 | 32 | 0 | 0 | Very low | 0 |
| 14 | 80 | 18 | 2 | 0 | Very low | 0 |
| 15 | 74 | 24 | 2 | 0 | Very low | 0 |
| 16 | 100 | 0 | 0 | 0 | Very low | 0 |
| 17 | 2 | 57 | 38 | 3 | Low | 0 |
| 18 | 1 | 27 | 62 | 10 | Medium | 1 |
| 19 | 36 | 47 | 17 | 0 | Low | 0 |
| 20 | 2 | 68 | 30 | 0 | Low | 0 |
| 21 | 0 | 56 | 41 | 3 | Low | 0 |
| 22 | 100 | 0 | 0 | 0 | Very low | 0 |
| 23 | 70 | 28 | 2 | 0 | Very low | 0 |
| 24 | 82 | 18 | 0 | 0 | Very low | 0 |
| 25 | 100 | 0 | 0 | 0 | Very low | 0 |
| 26 | 6 | 23 | 69 | 2 | Medium | 1 |
| 27 | 2 | 11 | 48 | 39 | Medium | 1 |
| 28 | 0 | 1 | 39 | 60 | High | 1 |
| 29 | 25 | 63 | 12 | 0 | Low | 0 |
| 30 | 0 | 0 | 17 | 83 | High | 1 |
| 31 | 70 | 28 | 2 | 0 | Very low | 0 |
| 32 | 0 | 0 | 7 | 93 | High | 1 |
| 33 | 0 | 0 | 4 | 96 | High | 1 |
| 34 | 0 | 1 | 30 | 69 | High | 1 |
| 35 | 0 | 0 | 14 | 86 | High | 1 |
| 36 | 0 | 0 | 3 | 97 | High | 1 |
| 37 | 0 | 0 | 5 | 95 | High | 1 |
| 38 | 99 | 1 | 0 | 0 | Very low | 0 |
| 39 | 0 | 0 | 13 | 87 | High | 1 |
| 40 | 99 | 1 | 0 | 0 | Very low | 0 |
| 41 | 0 | 0 | 24 | 76 | High | 1 |
| 42 | 95 | 5 | 0 | 0 | Very low | 0 |
| 43 | 0 | 0 | 13 | 87 | High | 1 |
| 44 | 100 | 0 | 0 | 0 | Very low | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 45 | 0 | 0 | 17 | 83 | High | 1 |
| 46 | 0 | 5 | 53 | 42 | Medium | 1 |
| 47 | 0 | 73 | 10 | 17 | Low | 0 |
| 48 | 97 | 3 | 0 | 0 | Very low | 0 |
| 49 | 22 | 62 | 16 | 0 | Low | 0 |
| 50 | 100 | 0 | 0 | 0 | Very low | 0 |
| 51 | 100 | 0 | 0 | 0 | Very low | 0 |
| 52 | 100 | 0 | 0 | 0 | Very low | 0 |
| 53 | 100 | 0 | 0 | 0 | Very low | 0 |
| 54 | 100 | 0 | 0 | 0 | Very low | 0 |
| 55 | 0 | 15 | 39 | 46 | High | 1 |
| 56 | 100 | 0 | 0 | 0 | Very low | 0 |
| 57 | 100 | 0 | 0 | 0 | Very low | 0 |
| 58 | 100 | 0 | 0 | 0 | Very low | 0 |
| 59 | 100 | 0 | 0 | 0 | Very low | 0 |
| 60 | 100 | 0 | 0 | 0 | Very low | 0 |
| 61 | 100 | 0 | 0 | 0 | Very low | 0 |
| 62 | 100 | 0 | 0 | 0 | Very low | 0 |
| 63 | 98 | 2 | 0 | 0 | Very low | 0 |
| 64 | 5 | 25 | 56 | 14 | Medium | 1 |
| 65 | 5 | 66 | 13 | 16 | Low | 0 |
| 66 | 100 | 0 | 0 | 0 | Very low | 0 |
| 67 | 97 | 3 | 0 | 0 | Very low | 0 |
| 68 | 0 | 0 | 5 | 95 | High | 1 |
| 69 | 100 | 0 | 0 | 0 | Very low | 0 |
| 70 | 100 | 0 | 0 | 0 | Very low | 0 |
| 71 | 19 | 8 | 73 | 0 | Medium | 1 |
| 72 | 0 | 0 | 3 | 97 | High | 1 |
| 73 | 0 | 0 | 18 | 82 | High | 1 |
| 74 | 0 | 0 | 7 | 93 | High | 1 |
| 75 | 0 | 0 | 3 | 97 | High | 1 |
| 76 | 0 | 0 | 39 | 61 | High | 1 |
| 77 | 0 | 4 | 30 | 66 | High | 1 |
| 78 | 0 | 0 | 2 | 98 | High | 1 |
| 79 | 0 | 0 | 9 | 91 | High | 1 |
| 80 | 0 | 74 | 6 | 20 | Low | 0 |
| 81 | 55 | 41 | 4 | 0 | Very low | 0 |
| 82 | 0 | 24 | 55 | 21 | Medium | 1 |
| 83 | 8 | 16 | 56 | 20 | Medium | 1 |
| 84 | 54 | 41 | 5 | 0 | Very low | 0 |
| 85 | 0 | 0 | 12 | 88 | High | 1 |
| 86 | 99 | 1 | 0 | 0 | Very low | 0 |
| 87 | 99 | 1 | 0 | 0 | Very low | 0 |
| 88 | 0 | 31 | 58 | 11 | Medium | 1 |
| 89 | 0 | 1 | 30 | 69 | High | 1 |
| 90 | 68 | 31 | 1 | 0 | Very low | 0 |
| 91 | 100 | 0 | 0 | 0 | Very low | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 92 | 65 | 32 | 3 | 0 | Very low | 0 |
| 93 | 0 | 4 | 32 | 64 | High | 1 |
| 94 | 100 | 0 | 0 | 0 | Very low | 0 |
| 95 | 0 | 0 | 3 | 97 | High | 1 |
| 96 | 0 | 0 | 22 | 78 | High | 1 |
| 97 | 0 | 55 | 24 | 21 | Low | 0 |
| 98 | 0 | 18 | 61 | 21 | Medium | 0 |
| 99 | 100 | 0 | 0 | 0 | Very low | 0 |
| 100 | 95 | 5 | 0 | 0 | Very low | 0 |
| 101 | 98 | 2 | 0 | 0 | Very low | 0 |
| 102 | 0 | 3 | 66 | 31 | Medium | 1 |
| 103 | 0 | 41 | 46 | 13 | Medium | 0 |
| 104 | 0 | 8 | 46 | 46 | Medium | 1 |
| 105 | 100 | 0 | 0 | 0 | Very low | 0 |
| 106 | 100 | 0 | 0 | 0 | Very low | 0 |
| 107 | 100 | 0 | 0 | 0 | Very low | 0 |
| 108 | 98 | 2 | 0 | 0 | Very low | 0 |
| 109 | 100 | 0 | 0 | 0 | Very low | 0 |
| 110 | 0 | 0 | 5 | 95 | High | 1 |
| 111 | 0 | 0 | 1 | 99 | High | 1 |
| 112 | 0 | 0 | 3 | 97 | High | 1 |
| 113 | 0 | 0 | 2 | 98 | High | 1 |
| 114 | 0 | 0 | 0 | 100 | High | 1 |
| 115 | 0 | 0 | 9 | 91 | High | 1 |
| 116 | 100 | 0 | 0 | 0 | Very low | 0 |
| 117 | 90 | 10 | 0 | 0 | Very low | 0 |
| 118 | 100 | 0 | 0 | 0 | Very low | 0 |
| 119 | 0 | 0 | 9 | 91 | High | 1 |
| 120 | 100 | 0 | 0 | 0 | Very low | 0 |
| 121 | 0 | 70 | 14 | 16 | Low | 0 |
| 122 | 0 | 0 | 27 | 73 | High | 1 |
| 123 | 100 | 0 | 0 | 0 | Very low | 0 |
| 124 | 0 | 0 | 8 | 92 | High | 1 |
| 125 | 0 | 0 | 8 | 92 | High | 1 |
| 126 | 100 | 0 | 0 | 0 | Very low | 0 |
| 127 | 100 | 0 | 0 | 0 | Very low | 0 |
| 128 | 0 | 0 | 7 | 93 | High | 1 |
| 129 | 100 | 0 | 0 | 0 | Very low | 0 |
| 130 | 100 | 0 | 0 | 0 | Very low | 0 |
| 131 | 0 | 65 | 33 | 2 | Low | 0 |
| 132 | 100 | 0 | 0 | 0 | Very low | 0 |
| 133 | 100 | 0 | 0 | 0 | Very low | 0 |
| 134 | 100 | 0 | 0 | 0 | Very low | 0 |
| 135 | 100 | 0 | 0 | 0 | Very low | 0 |
| 136 | 0 | 73 | 24 | 3 | Low | 0 |
| 137 | 100 | 0 | 0 | 0 | Very low | 0 |
| 138 | 100 | 0 | 0 | 0 | Very low | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 139 | 100 | 0 | 0 | 0 | Very low | 0 |
| 140 | 100 | 0 | 0 | 0 | Very low | 0 |
| 141 | 97 | 3 | 0 | 0 | Very low | 0 |
| 142 | 100 | 0 | 0 | 0 | Very low | 0 |
| 143 | 100 | 0 | 0 | 0 | Very low | 0 |
| 144 | 100 | 0 | 0 | 0 | Very low | 0 |
| 145 | 100 | 0 | 0 | 0 | Very low | 0 |
| 146 | 0 | 67 | 9 | 24 | Low | 0 |
| 147 | 100 | 0 | 0 | 0 | Very low | 0 |
| 148 | 0 | 0 | 30 | 70 | High | 1 |
| 149 | 100 | 0 | 0 | 0 | Very low | 0 |
| 150 | 100 | 0 | 0 | 0 | Very low | 0 |
| 151 | 4 | 2 | 25 | 69 | High | 1 |
| 152 | 100 | 0 | 0 | 0 | Very low | 0 |
| 153 | 100 | 0 | 0 | 0 | Very low | 0 |
| 154 | 0 | 4 | 46 | 50 | High | 1 |
| 155 | 0 | 4 | 52 | 44 | Medium | 1 |
| 156 | 3 | 2 | 14 | 81 | High | 1 |
| 157 | 4 | 2 | 26 | 68 | High | 1 |
| 158 | 0 | 0 | 23 | 77 | High | 1 |
| 159 | 0 | 0 | 7 | 93 | High | 1 |
| 160 | 86 | 14 | 0 | 0 | Very low | 0 |
| 161 | 94 | 6 | 0 | 0 | Very low | 0 |
| 162 | 100 | 0 | 0 | 0 | Very low | 0 |
| 163 | 100 | 0 | 0 | 0 | Very low | 0 |
| 164 | 100 | 0 | 0 | 0 | Very low | 0 |
| 165 | 100 | 0 | 0 | 0 | Very low | 0 |
| 166 | 95 | 5 | 0 | 0 | Very low | 0 |
| 167 | 100 | 0 | 0 | 0 | Very low | 0 |
| 168 | 100 | 0 | 0 | 0 | Very low | 0 |
| 169 | 88 | 12 | 0 | 0 | Very low | 0 |
| 170 | 0 | 70 | 30 | 0 | Low | 0 |
| 171 | 0 | 1 | 44 | 55 | High | 1 |
| 172 | 0 | 0 | 11 | 89 | High | 1 |
| 173 | 97 | 3 | 0 | 0 | Very low | 0 |
| 174 | 99 | 1 | 0 | 0 | Very low | 0 |
| 175 | 96 | 4 | 0 | 0 | Very low | 0 |
| 176 | 97 | 3 | 0 | 0 | Very low | 0 |
| 177 | 91 | 9 | 0 | 0 | Very low | 0 |
| 178 | 97 | 3 | 0 | 0 | Very low | 0 |
| 179 | 91 | 9 | 0 | 0 | Very low | 0 |
| 180 | 19 | 16 | 64 | 1 | Medium | 1 |
| 181 | 9 | 2 | 52 | 37 | Medium | 1 |
| 182 | 27 | 55 | 18 | 0 | Low | 0 |
| 183 | 47 | 48 | 5 | 0 | Low | 0 |
| 184 | 90 | 10 | 0 | 0 | Very low | 0 |
| 185 | 0 | 0 | 0 | 100 | High | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 186 | 0 | 0 | 0 | 100 | High | 1 |
| 187 | 0 | 0 | 0 | 100 | High | 1 |
| 188 | 0 | 0 | 0 | 100 | High | 1 |
| 189 | 0 | 0 | 0 | 100 | High | 1 |
| 190 | 0 | 0 | 0 | 100 | High | 1 |
| 191 | 0 | 0 | 0 | 100 | High | 1 |
| 192 | 0 | 0 | 0 | 100 | High | 1 |
| 193 | 0 | 0 | 0 | 100 | High | 1 |
| 194 | 0 | 0 | 0 | 100 | High | 1 |
| 195 | 16 | 61 | 23 | 0 | Low | 0 |
| 196 | 0 | 0 | 26 | 74 | High | 1 |
| 197 | 0 | 0 | 5 | 95 | High | 1 |
| 198 | 0 | 0 | 0 | 100 | High | 1 |
| 199 | 0 | 0 | 18 | 82 | High | 1 |
| 200 | 0 | 0 | 8 | 92 | High | 1 |
| 201 | 0 | 0 | 0 | 100 | High | 1 |
| 202 | 0 | 0 | 0 | 100 | High | 1 |
| 203 | 0 | 0 | 0 | 100 | High | 1 |
| 204 | 0 | 0 | 0 | 100 | High | 1 |
| 205 | 0 | 0 | 0 | 100 | High | 1 |
| 206 | 0 | 0 | 0 | 100 | High | 1 |
| 207 | 0 | 0 | 0 | 100 | High | 1 |
| 208 | 0 | 0 | 6 | 94 | High | 1 |
| 209 | 0 | 0 | 2 | 98 | High | 1 |

Table 1: Classification results for all the springs.