# SOUND TRANSIT LINK LIGHT RAIL PROJECT

*North Link*
*Hi-Lo Mitigation EMI Report*

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# 1 FOREWORD

This report presents the results of investigations of the sources of stray magnetic fields ("B-fields") likely to be caused by the North Link rail transit line operating through the University of Washington campus in Seattle. It makes recommendations for design techniques and operational procedures for minimizing the levels of those fields. This report summarizes the results of a number of earlier reports, analyses, studies, and tests completed by numerous individuals, including the author of this report, Dr. F. Ross Holmstrom. Additional inputs were provided by Dr. Luciano Zaffanella of Enertech; Dr. David Fugate of ERM, Inc.; Dr. T. Dan Bracken, EMI consultant to the UW; Chris Fassero, James Irish, Tracy Reed, and Steve Proctor of Sound Transit; and LTK systems engineers.

## 2 EXECUTIVE SUMMARY

While offering many potential benefits, North Link has the potential to affect research activities at a number of UW laboratories. Magnetic fields, arising from the propulsion currents measured in the thousands of amperes flowing from power substations to the electrically powered trains, could disrupt sensitive apparatus. Perturbation to Earth's magnetic field, caused by the motion of steel bodied rail cars passing near laboratories, is another potential source of magnetic field disruption.

Magnetic field strength due to propulsion currents is referred to as $B_{prop}$ in this report, and magnetic field strength due to geomagnetic field perturbations is referred to as $B_{ptb}$. Both are collectively referred to as "stray B-fields", and are stated in units of gauss (G) or milli-gauss (mG). In the SI system of units widely used for scientific and technical work magnetic field strength is stated in units of tesla (T). One T equals $10^4$ G. By way of orienting the reader to B-field magnitudes, note that in the northern US Earth's B-field has a magnitude of approximately 0.6 G. And a straight conductor carrying 1000 amperes of current will produce a B-field circulating around it with a strength of 0.16 G at a distance of one meter (3.28 ft). Because of their time varying nature, stray B-fields with levels as small as 0.1 mG, or one six thousandth of Earth's B-field level, could compromise the accuracy of some of the UW's most sensitive research equipment.

If no special techniques are employed to attenuate $B_{prop}$ field levels, they will form the predominant part of stray B-fields. Through careful design of the traction power system, $B_{prop}$ fields can be greatly reduced, leaving the $B_{ptb}$ fields to predominate. The only practical way of dealing with the $B_{ptb}$ fields is to allow sufficient distance between tracks and sensitive laboratories.

General practice in the transit field to date has been to not employ techniques to attenuate $B_{prop}$ fields. The only tool used to provide acceptable field levels at sensitive laboratory sites has been to locate laboratories and transit tracks far enough apart. One manufacturer of sensitive lab equipment similar to that employed at the UW specifies a separation of 800 ft (244 meters) between rail transit tracks and the equipment.

Without mitigation, the thousands of amperes of propulsion current flowing in the loops of conductor formed by the overhead contact wire and running rails with LRVs traversing the area, would lead to $B_{prop}$ field levels that would exceed UW specs practically everywhere on campus, no matter where on campus North Link were located. The $B_{prop}$ fields from these large loops have strength proportional to the height of the loops times current carried, and inversely proportional to the square of the distance from the track.

To mitigate $B_{prop}$ fields, North Link is considering a technique, locally dubbed "Hi-Lo mitigation", that is essentially the same as that employed by a light rail line in Bielefeld, Germany running past the University of Bielefeld, in operation for a number of years; and another presently in planning for the Cross County extension of the St. Louis

MetroLink, to run past the main campus of Washington University in St. Louis, expected to commence service in 2006.

The UW and Sound Transit are considering a route for North Link through the UW campus. The route and approximate limits of mitigation are shown in Figure 2.1.

The following assumptions are used in this report as a basis for calculations:

- Four car trains operating at full current of 2800 Amps, one train in each direction in EMI Mitigation area, one train in each direction north of and one train in each direction south of EMI mitigation area
- Contact wire wear of 30% from new condition
- Special considerations to minimize wire splice contact resistance
- Minimizing stray current loss through ground paths

A special technique for measuring the health of rail-to-ground resistance is being used for Central Link Light Rail and will be utilized for North Link. The health of the rail-to-ground resistance is a major deterrent to stray current propagation. Specialized equipment will be located at trackside near traction power substations that will remotely monitor the integrity of the insulation properties of the running rail fasteners.

Table 2.1 gives the UW requested stray B-field levels at critical laboratories, the B-field levels that would result if no special B-field mitigation techniques were employed and stray B-field levels predicted to be achieved by Hi-Lo B-field mitigation. As can be seen from the table, UW desired stray B-field levels can be met at all but Wilcox and Roberts Halls and the ME Building and Annex. These failing locations and B-field values are highlighted in bold in Table 2.1. Without B-field mitigation it is seen that stray B-field level(s) exceed the UW thresholds at practically all critical lab locations.

B-field levels resulting from employment of Hi-Lo B-field mitigation are shown two ways in Table 2.1; first assuming that the geographical extent over which Hi-Lo mitigation techniques are employed is infinite; and again assuming that the Hi-Lo mitigation region extends north only as far as a point on the North Link right of way just SW of the intersection of University Way and NE 45th St., and south for a distance of approx. 450 meters (1500 ft) from the southern end of the University of Washington station. The stray B-field values resulting from the finite extent of Hi-Lo mitigation include contributions from trains operating north of the NE 45th St. station and south of the University of Washington station simultaneously with trains running northbound and southbound through the UW campus.

Two additional mitigation measures that could be used if necessary are limiting maximum power draw of trains passing under the University campus and limiting light rail operations to only one train under the campus at a time. However, Sound Transit has indicated that both of these measures would be used only if absolutely necessary to reduce impacts to the most sensitive buildings. This is because they would restrict the

ability of the system to carry higher passenger loads in the future and during special events at Husky Stadium and make operations more difficult overall.

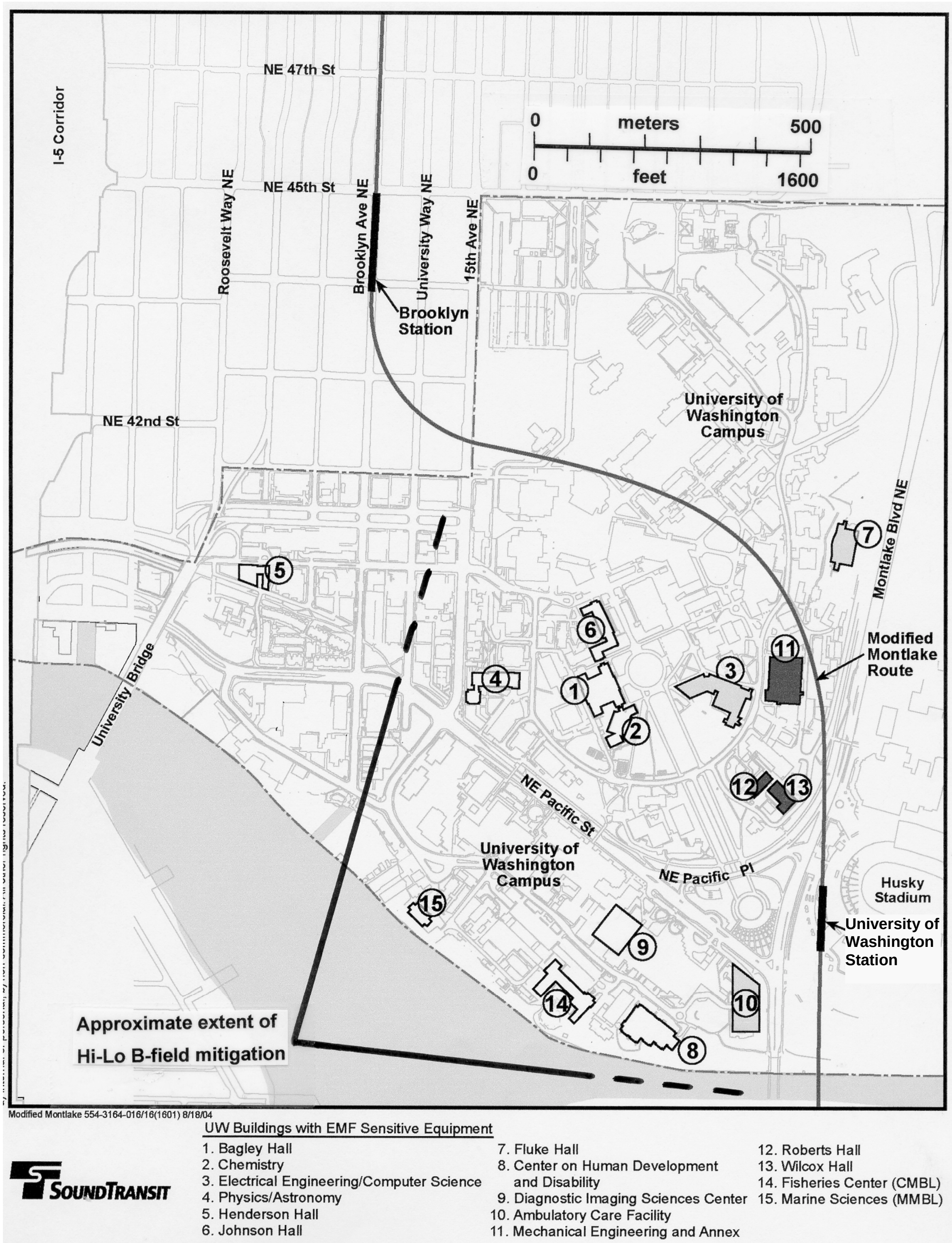


**Figure 2.1** UW campus map showing laboratory buildings with critical stray B-field requirements, the North Link right-of-way, and the approximate required extent of Hi-Lo B-field mitigation

**Table 2.1** Mitigated and unmitigated North Link stray B-field levels at critical UW labs.

| **Lab** | **UW B-field spec levels, mG** | **Unmitigated B-field mG** | **Infinite-extent Hi-Lo mitigated B-field mG*** | **Finite-extent Hi-Lo mitigated B-field mG***** |
|---|---|---|---|---|
| Bagley Hall | 0.1 | **0.562** | 0.033 | 0.076 |
| Chemistry Bldg. | 0.1 | **0.530** | 0.032 | 0.066 |
| EE-CS | 5.0 | 3.98 | 0.184 | 0.217 |
| Physics-Astron. | 0.5 | 0.376 | 0.017 | 0.070 |
| Johnson Hall | 5.0 | 1.144 | 0.059 | 0.110 |
| Fluke Hall | 0.3 | **4.27** | 0.223 | 0.256 |
| **ME Bldg.** | 0.2 | **18.75** | **0.875** | **0.907** |
| **ME Rm. 135** | 0.2 | **6.37** | **0.300** | **0.332** |
| **ME Annex** | 0.2 | **36.3** | **1.598** | **1.630** |
| **Roberts Hall** | 0.1 | **6.01** | **0.284** | **0.319** |
| **Wilcox Hall** | 0.1 | **17.29** | **0.810** | **0.846** |
| Henderson** | ** | 0.370 | 0.016 | 0.142 |
| CHDD | 0.3 | **0.948** | 0.056 | 0.183 |
| Diagn. Imaging | 5.0 | 0.494 | 0.030 | 0.087 |
| Surgery Pavilion | 1.0 | **5.44** | 0.344 | 0.471 |
| Fisheries Ctr. | 0.1 | **0.315** | 0.019 | 0.093 |
| Marine Science | 1.0 | 0.089 | 0.005 | 0.045 |
| **Roberts-W. half** | 0.1 | **4.37** | **0.199** | **0.234** |

Notes: *Hi-Lo mitigated B-field was calculated with 30 percent overhead contact wire wear.
**At Henderson Hall UW spec is |dB,tot/dt| Ò0.2 mG/sec.
***Includes B-fields from trains operating north and south of campus.

Levels shown in bold in Table 2.1 are levels that exceed UW spec B-field levels at the respective labs. Lab names shown in bold indicate that Hi-Lo mitigated B-field levels at the respective labs do not meet UW specs. Note that for the Hi-Lo mitigation endpoints chosen for this modeling the labs that passed the UW spec limits for the case of Hi-Lo mitigation of infinite extent also passed when the extent was made finite.

The specific results for B-fields mitigated by a Hi-Lo mitigation region of finite extent given in Table 2.1 depend strongly on the chosen Hi-Lo mitigation endpoints as well as on the assumptions of worst-case train currents locations for trains operating north and south of the campus.

The final northern and southern ends of the Hi-Lo mitigation will be determined at the time of final design and will include refined estimates of worst case train currents and locations for trains on campus and north and south of the campus. With the above endpoints the Hi-Lo mitigation region stretches approx. 1800 meters (5900 ft) along the curved North Link right of way. However, more refined modeling could result in the estimate of required length decreasing to approximately 1500 meters (5000 ft).

The B-field modeling reported here for the Hi-Lo B-field mitigated case has been done assuming that the overhead contact wire wear had reduced its cross sectional area by 30 percent from its initial value.

Table 2.2 gives the value of a Hi-Lo mitigation "compliance factor" CF for each of the four most critical laboratories. Based on a combination of UW spec level and location, of the labs at which UW spec B-field levels can be met, these labs are Bagley Hall, the Chemistry Bldg., Fluke Hall and the Fisheries Center. CF is the number by which calculated northbound plus southbound propulsion B-fields arising from currents in the Hi-Lo mitigated region must be multiplied to bring total stray B-field up to the UW specified level. The factor must have a value greater than 1 for total stray B-fields to meet the UW requested thresholds. This factor serves as an overall indication of the degradation from modeled behavior that can occur before overall stray B-fields fail to

**Table 2.2** Values of Hi-Lo mitigation compliance factor CF for four critical UW labs.

| Lab | CF |
|---|---|
| Bagley Hall | 2.0 |
| Chemistry Bldg. | 2.3 |
| Fluke Hall | 1.3 |
| Fisheries Center | 2.0 |

comply with the UW limits. A larger factor indicates less sensitivity and greater leeway. CF was calculated by arbitrarily multiplying calculated Hi-Lo mitigated propulsion B-fields by a factor before adding those fields to the others to produce the overall totals, and then by increasing the value of the factor until the stray B-field totals equaled the UW spec limits. The minimum CF recommended to comply with UW specified B-field limits and allow a sufficient factor of safety is 2.0.

The purpose of the extensive modeling performed to yield the results summarized in Table 2.1 is to document the prediction that Hi-Lo B-field mitigation can produce greatly reduced propulsion B-field levels where needed. In practice at most critical laboratories the peak levels of propulsion B-field that actually occur will be due to the distances from those labs to the endpoints of Hi-Lo mitigation near the north and south ends of the campus.

The effectiveness of Hi-Lo B-field mitigation depends upon the avoidance of propulsion currents leaking into the ground. A special technique for measuring the health of rail-to-ground resistance is being used for Central Link Light Rail and will be utilized for North Link. The health of the rail-to-ground resistance is a major deterrent to stray current propagation. Specialized equipment will be located at trackside near traction power substations that will remotely monitor the integrity of the insulation properties of the running rail fasteners.

The calculations summarized in Table 2.1 were performed assuming conductor sizes and positions as given in the circuit design presently regarded as the most likely one to be implemented. Whereas prior modeling of stray B-fields was performed to assess the feasibility of various routes and B-field mitigation techniques, the modeling for this report was performed including the effects of the industry standard value of 30 percent maximum contact wire wear. Consequently the total stray B-field values are larger than those previously published.

The Hi-Lo mitigation technique uses a large diameter cable buried beneath the center of each track to carry most of the current from substation to train, while the remaining fraction of current will flow in the overhead contact wire. Current will flow in one sense around the loop formed by overhead contact wire, train and running rails, and in the opposite sense around the loop formed by the buried cable, train and running rails. Since these loops are located close together, their magnetic fields will be nearly equal in spatial variation and their field lines will point in practically opposite directions.

If the product of overhead contact wire height above the rails times its electrical conductance equals the product of buried cable depth below the rails times its conductance, the $B_{prop}$ fields from the top and bottom loops will be nearly equal in magnitude and opposite in direction, and they will largely cancel. The degree of reduction of $B_{prop}$ fields depends on the precision with which the fields from the top and bottom loops can be made to cancel.

An array of "riser cables" spaced tens of meters apart down the track will carry train current from the buried cable up to the overhead contact wire at points very near the train. Currents in the risers nearest the train will lead to additional $B_{prop}$ fields of a very localized nature that are smaller and fall off more rapidly with distance than the original unmitigated $B_{prop}$ fields.

At points on the right-of-way well away from critical laboratories standard propulsion circuitry will be used, with currents flowing to trains through the normal overhead messenger and contact wires. The locations of the end points of Hi-Lo mitigation depend upon B-fields caused by semi-infinite current carrying loops of full contact wire height falling off sufficiently with distance so that maximum stray B-field levels at critical labs are not exceeded. The end of Hi-Lo mitigation at the north end of campus is set by required distance from Bagley Hall, and at the south end by required distance from the Fisheries Center. The approximate required extent of Hi-Lo B-field mitigation is noted in Figure 2.1. A final determination of the extent of Hi-Lo mitigation will be made at the time of final design.

In November 2003, measurements were made on the UW campus to assess the existing magnetic field environment at locations near sensitive laboratories. These results are summarized in this report. Existing stray B-field levels on the UW campus arising from geomagnetic field perturbations caused by motor vehicles were examined and measured in order to obtain information on the presently existing stray B-field environment on the campus. The focus of measurements was on $B_{ptb}$ levels arising from the passage of articulated diesel transit buses with a length of approx. 60 ft (18 m). These ply Stevens Way and certain connecting roads in large number, especially during rush hours, and are among the largest of vehicles to be found routinely on the campus.

It was found that the Mechanical Engineering Bldg. is so close to Stevens way that existing $B_{ptb}$ levels from the buses already exceed the UW stray B-field specs throughout much of the building. Other buildings are farther from Stevens Way but have adjacent parking lots. Cars, vans and light trucks in these parking lots were found to yield $B_{ptb}$ levels considerably higher than the UW stray B-field specs at the exterior walls of Fluke, Roberts and Wilcox Halls. Similar B-field levels could be expected in the ME Annex. While it is true that the $B_{ptb}$ fields arising from cars, vans and light trucks fall off with distance much more rapidly than those from large transit buses, these results nonetheless indicate inconsistency in the establishment of the UW's stray B-field specs. If researchers envision the flexibility to locate the most B-field sensitive instruments anywhere in the interior of many UW buildings, changes will have to be made to traffic and parking nearby these buildings.

Although the purpose of this report is to provide technical information and not make recommendations, the author will discuss a number of implications of the results given in Table 2.1. Given the alignment of the North Link right-of-way considered in this report, North Link $B_{ptb}$ field levels by themselves will exceed the UW spec limits for overall stray B-fields in Wilcox Hall, the ME Annex, and that part of the ME Bldg. closest

to the North Link right-of-way. Bus traffic on Stevens Way already causes $B_{ptb}$ levels above the total UW B-field spec limits in the remainder of the ME Bldg.

If the present and future B-field sensitive research activities in ME, ME Annex, Wilcox, and Roberts are moved elsewhere, UW B-field specs could be met at all critical UW labs. The lab with the lowest $B_{prop}$ compliance factor would then be Fluke Hall, with a factor of 1.3, meaning that an increase in $B_{prop}$ levels by that factor would bring overall stray “B-fields to that level at Fluke Hall.

The long-term effectiveness of the program to mitigate $B_{prop}$ fields will depend specifically on the ability to achieve and maintain cancellation of the $B_{prop}$ fields from the upper and lower loops in the Hi-Lo B-field mitigation circuit. The wear of the overhead contact wire will be the chief predictable cause of variation of $B_{prop}$ field levels over time. Possible unpredictable causes include current imbalances caused by propulsion currents leaking through electrically degraded rubber rail cushions into the ground, and the deterioration of electrical cable splices, leading to increased values of contact resistance, and leading in turn to changes in current flow patterns.

Assurance of the long term effectiveness of stray B-field mitigation will require an effective long term preventive and corrective maintenance program. Small problems will best be dealt with before they can worsen and become disruptive. Monitoring of stray B-fields will serve as one important input to the maintenance program. The monitoring could employ permanently installed magnetic field sensors, coupled to interface computers to send the data over the internet to a centralized point. As an alternative, periodic B-field monitoring using portable B-field sensors could be employed as well when more flexibility is needed. Data analysis of the type used during testing for this program, but more automated, could provide output for assessment of B-field mitigation performance on either a continuous, real-time basis or periodic basis. The B -field sensors might be housed in suitable corners of existing UW buildings. Final development of the B-field monitoring program will require an analysis of potential monitoring sites, both permanent and temporary, on the UW campus, existing and future locations of sensitive lab equipment, and the existing and future non-North Link sources of stray B-fields that could interfere with monitoring.

We believe that with careful testing, analysis, design and construction, coupled with long term diagnosis and maintenance, the objectives for North Link stray B-field mitigation can be met.