Evaluation of Ecological Risk Associated with Groundwater Discharge of CCR-Derived Constituents to Surface Water

Joseph Robb, P.G.[1]

[1]ERM, One Beacon Street, 5th Floor, Boston, MA 02108

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ABSTRACT

Utilities faced with new federal coal combustion residual (CCR) regulations are required to design and implement groundwater monitoring programs at CCR management structures. The migration of CCR-impacted groundwater from these structures and ultimate discharge to surface water bodies is an ongoing concern as a result of the location of many coal-fired generating stations sited near surface water bodies. The potential fate and associated risk of CCR impacted groundwater discharging to surface water requires an understanding of the hydrogeologic and geochemical interactions across the interface. The presence of ecological receptors in surface water influences the identification of relevant risk standards and triggers the need for site-specific evaluation of potential ecological risk. A case study demonstrating the site-specific approach is provided below.

INTRODUCTION

This paper details a case study of a coal fired generating station on the shore of Lake Michigan where plumes of boron and selenium in groundwater discharge to the groundwater-surface water interface. The presence of federally-designated critical habitat for an endangered shorebird heightened regulatory scrutiny in this area. The strategy for developing the Conceptual Site Model, and establishing background groundwater and surface water quality data will be explained, and techniques used to evaluate and address site-specific ecological risk are discussed.

CONCEPTUAL SITE MODEL

The preliminary conceptual site model (CSM) was based on the site history and known facility operations, regional geologic and hydrogeologic studies and a preliminary identification of potential receptors. Highlights of the CSM at the outset of the site investigation process include the following:

Site History and Facility Operations

A 604 MW coal-fired electric generating plant (Facility) is located on an approximately 350-acre parcel (142 hectares), and has been in operation since 1962. The Facility is situated in an industrial area along the shoreline of Lake Michigan. Predominantly non-hazardous waste streams including bottom ash and fly ash have been generated by facility operations. Relatively small quantities of CCR derived from facility maintenance operations have been periodically staged in the southwest corner of the Facility reportedly since 1986 in an unpaved and uncovered area (Figure 1).

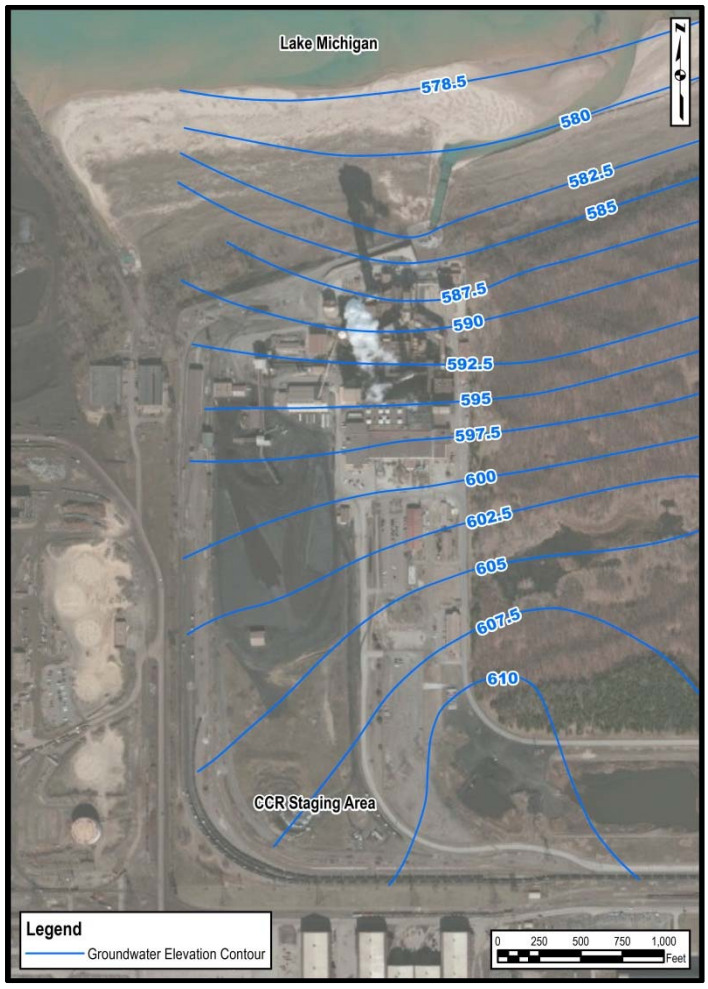

Figure 1. Satellite photograph of the Facility adjacent to Lake Michigan.

Site Geology and Hydrogeology

Throughout the southern Lake Michigan region, regional studies have identified shale and carbonate bedrock of Mississippian, Devonian and Silurian age. Overlying the bedrock strata are unconsolidated glacial, lacustrine, eolian and paludal sediments of Holocene and Pleistocene age. Four separate aquifers have been identified within the unconsolidated sediments, and the surficial aquifer (i.e., the aquifer closest to the land surface) consists primarily of lacustrine and eolian sands, is unconfined in most areas, and ranges in saturated thickness from 0 to greater than 24 meters (m)[1].

At the Facility, the surficial aquifer consists primarily of dune beach and lacustrine sands, and the depth to groundwater ranges from 0 to greater than 12 meters. A laterally continuous confining layer comprised of low permeability till and glacial lacustrine silt and clay layer underlies the surficial aquifer. No confining layers were observed above the phreatic surface and the saturated thickness of the unconfined surficial aquifer was observed to range from 13 m beneath the CCR staging area to approximately 5 m adjacent to Lake Michigan (Figure 2).

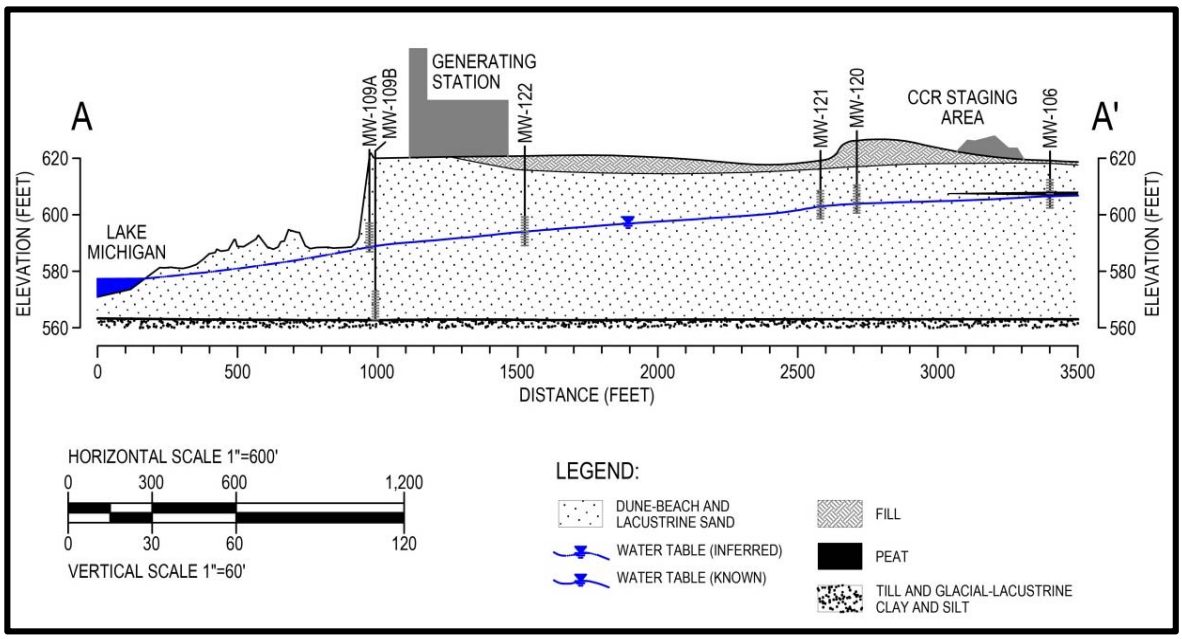

Figure 2. Geologic cross section showing shallow unconfined aquifer, CCR storage area and Lake Michigan

Monitoring of nested shallow/deep wells within the surficial aquifer showed no significant vertical hydraulic gradients near the Facility. Horizontal hydraulic gradients indicate groundwater flows from the CCR staging area in the southern part of the Facility to the north where it discharges into Lake Michigan (Figure 1). The average linear groundwater velocity was estimated to range from 0.2 to 0.4 m per day, based on a hydraulic conductivity[2] of 1.6×10^{-4} cm/sec, measured hydraulic gradients ranging from 0.005 to 0.01, and an assumed effective porosity of 0.35. This suggests the time required for groundwater to flow from the CCR disposal area to Lake Michigan (approximately 915 m), could range from 6 to 13 years.

Potential Ecological Receptors and Relevant Screening Criteria

The preliminary CSM identified shorebirds as potential ecological receptors within the Lake Michigan beach habitat. Based on regional hydrogeologic studies[1,2], it was assumed that the surficial aquifer extends to and underneath Lake Michigan, and shallow groundwater discharges to Lake Michigan at and beyond the shoreline. For the purpose of evaluating potential exposures, groundwater results were compared to Great Lakes Initiative (GLI) criteria (IDEM, 2002), which are regional water quality criteria that are protective of aquatic life, wildlife and human health.

CCR Constituents in Groundwater

The physical handling characteristics of fly ash generated from periodic cleaning of boilers and ductwork prevented management of the material along with the facility's fly ash derived from the electrostatic precipitators. This "maintenance ash" was temporarily staged in the southwest corner of the facility prior to off-site disposal in a permitted landfill. Materials were staged directly on the ground surface and were exposed to precipitation prior to off-site disposal. Based upon waste stream knowledge, historic residuals management practices in the operating area of the site, groundwater flow direction, plume geometry, and the constancy of detections above the GLI, the likely source of the boron and selenium plumes identified at the Facility is the temporary staging of coal combustion byproducts in the southwest corner of the facility.

Figure 3. Maintenance Ash Storage Area
Source: AMEC Earth and Environmental

Based on quarterly monitoring well sampling performed from 2005 to 2009, and direct push sampling campaign performed on the beach in 2009, boron and selenium were detected in groundwater above their GLI criteria of 1,600 ug/L and 4.61 ug/L, respectively. Both boron and selenium are expected to be present in anionic forms; boron as borate compounds[3] and selenium as selenite and selenate anions[4]. Boron is expected to sorb only minimally to the glacially derived sands. Given the generally aerobic conditions present in the surficial aquifer, selenium is not expected to be reduced to less soluble forms along the flow path to Lake Michigan.

Boron in groundwater extends from the ash staging area northward to Lake Michigan (Figures 4 and 5). Groundwater data from the industrial facility to the south indicate there is no anthropogenic source of boron upgradient of the Facility. The concentration of boron within the plume core typically exceeded the background boron concentration (120 ug/L) by an order of magnitude, and based upon the four years of monitoring data, the plume appears to be stable. The concentration of boron drops below the GLI criteria prior to discharge to Lake Michigan. The dilution of the plume prior to discharge to the lake is likely due to the mixing of lake water and groundwater within the shallow aquifer resulting from wave break on the beach in this high energy coastal environment.

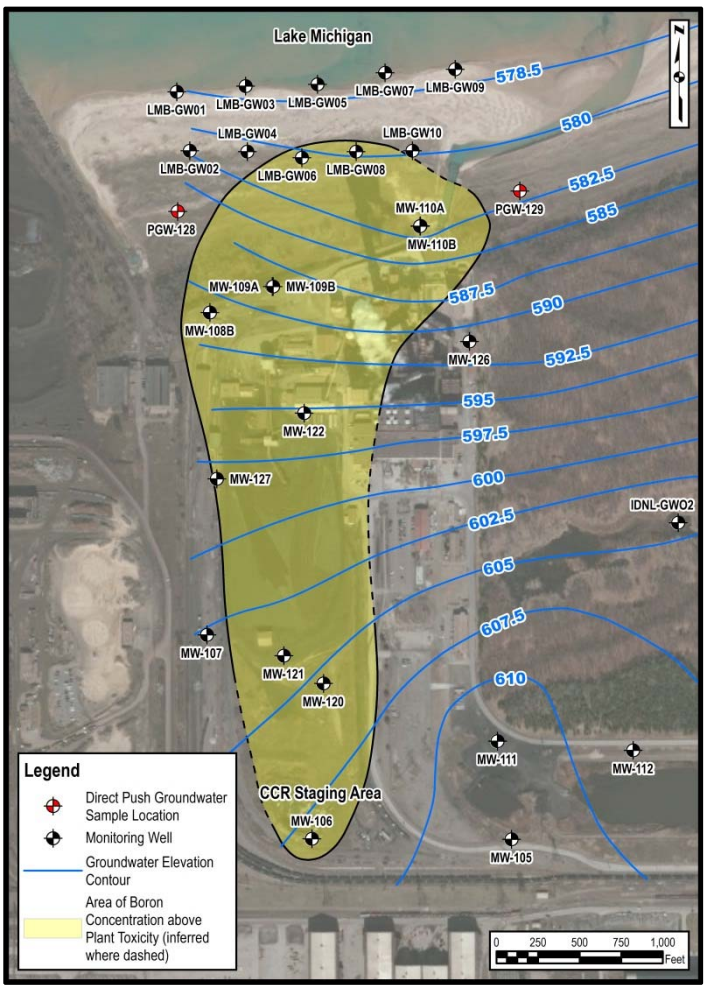

Figure 4. Extent of Boron in Surficial Aquifer

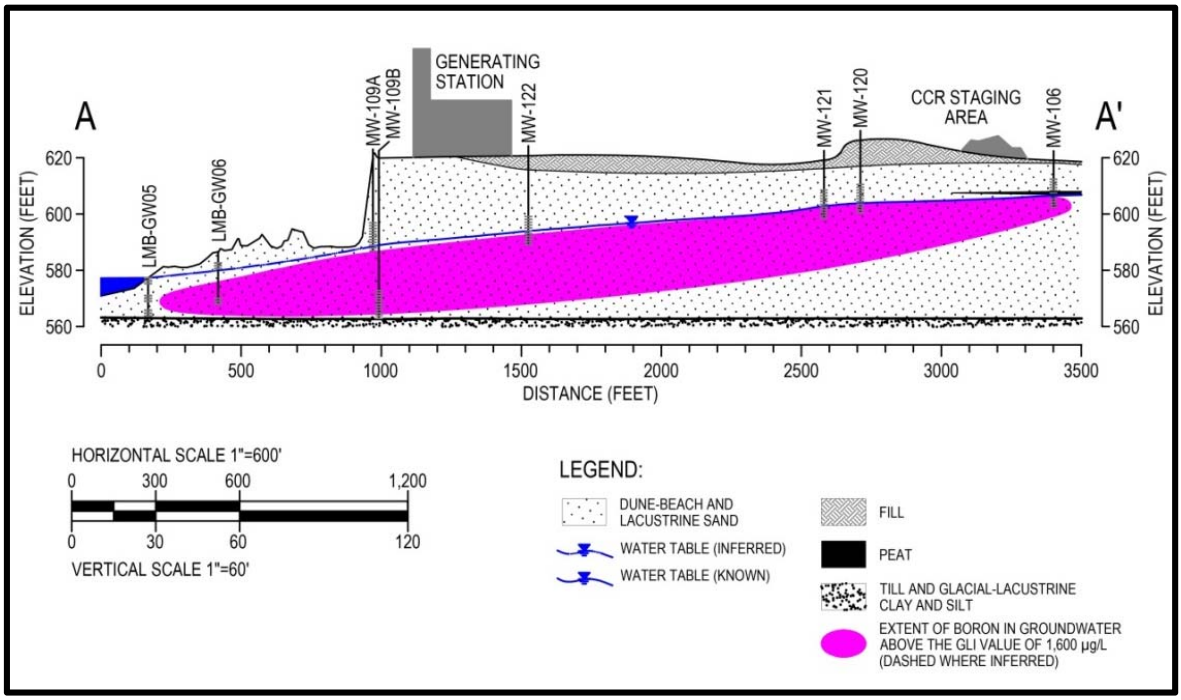

Figure 5. Extent of Boron in the Surficial Aquifer – Cross Section

Selenium above the GLI criteria of 4.61 ug/L extends from the ash staging area northward to Lake Michigan (Figures 6 and 7). Groundwater data from the industrial facility to the south indicate there is no anthropogenic source of selenium upgradient of the Facility. A separate smaller selenium plume was identified in the northeast corner of the Facility, and appears to have also originated from the CCR staging area based on groundwater flow directions. The concentration of selenium within the plume core typically exceeded the background concentration (1 ug/L) by an order of magnitude, and based upon the four years of monitoring data, both plumes appear to be stable. The concentration of selenium drops below the GLI criteria prior to discharge to Lake Michigan, for the same hydraulic reasons described above for boron.

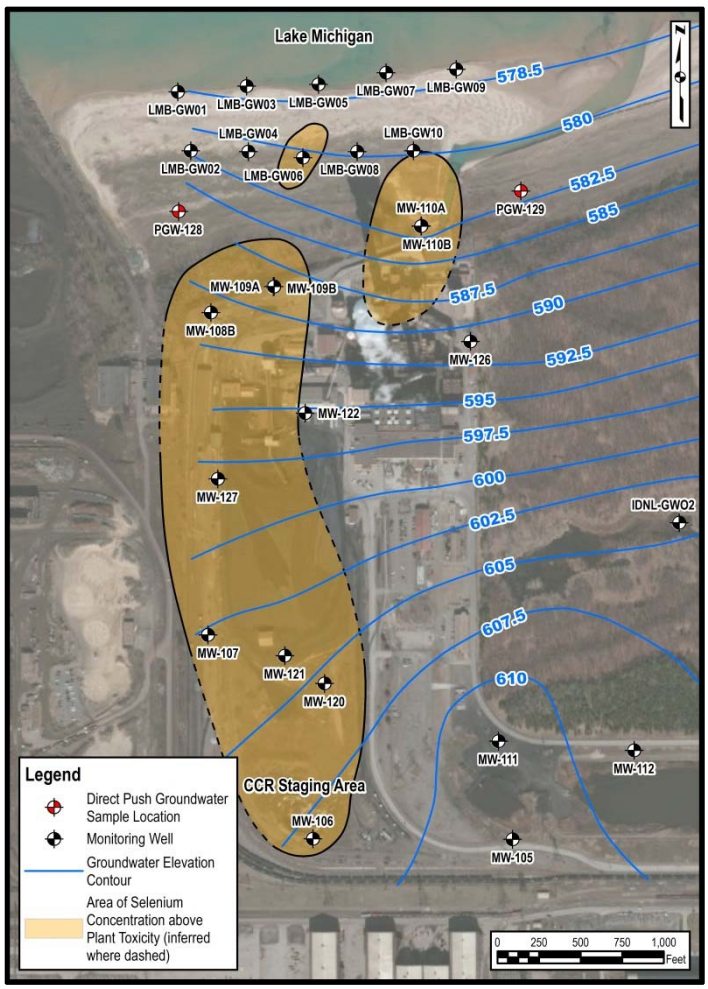

Figure 6. Extent of Selenium in Surficial Aquifer

ECOLOGICAL RISK ASSESSMENT

During the plume delineation process, the United States Fish and Wildlife Service and the United States Environmental Protection Agency (USEPA) indicated that the beach north of the Facility had been designated as critical habitat for the piping plover; an endangered shorebird that feeds along beaches and tidal flats. Given the potential for CCR-related constituents from the Facility to be present in groundwater near the beach surface, it was necessary to evaluate the potential for invertivorous birds, such as the piping plover, who may feed at the Lake Michigan Beach to be exposed to constituents in groundwater taken up by invertebrates living in the sand.

In order to determine if the concentration of boron, selenium and other CCR-related constituents could present risks to shorebirds including the piping plover, surface water and sediment samples were collected to support an ecological risk assessment. Groundwater samples during the 2009 direct push sampling described above were also used for the ecological risk assessment. The groundwater samples were collected from temporary well screens installed from 0 to 0.6 meters below the beach surface in the surf zone where piping plovers might feed. Results from the groundwater, surface water and sediment samples were used as input into a food web model prepared for the piping plover.

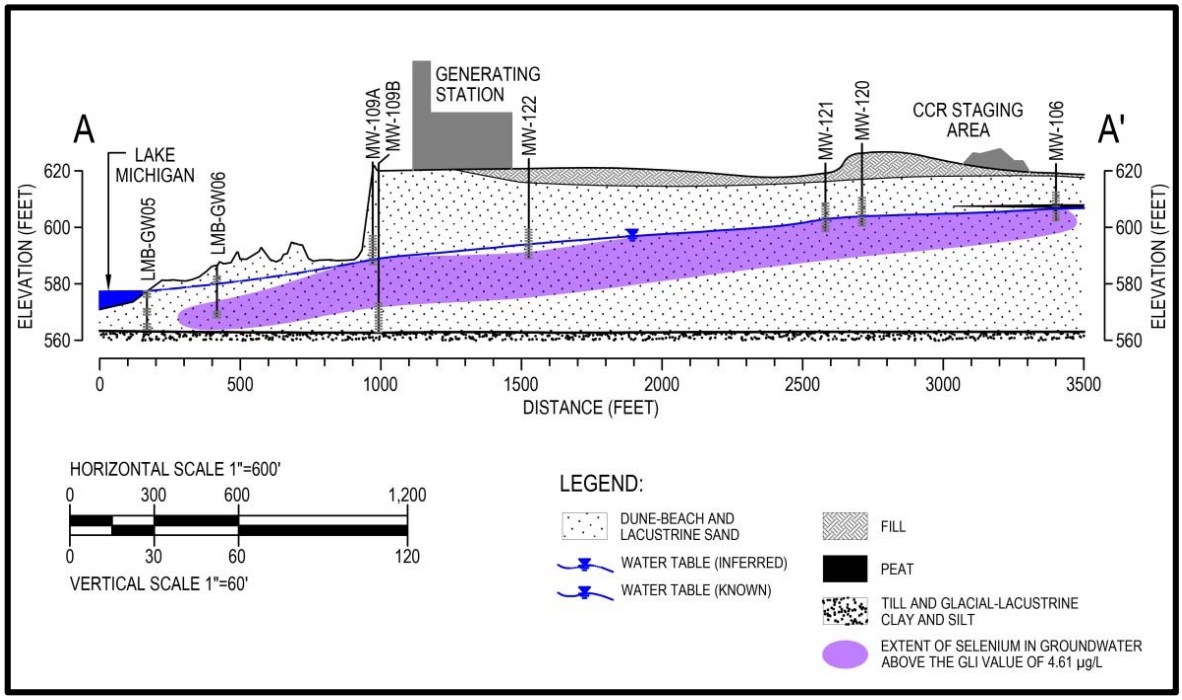

Figure 7. Extent of Selenium in the Surficial Aquifer – Cross Section

The food web model incorporated plover-specific information about selected biological characteristics and behaviors, such as:

- Sediment, invertebrate and water ingestion rates; and
- The size of the receptor's home range relative to the size of the habitat.

Exposure parameter values were obtained from EPA sources and from the scientific literature. The exposure doses estimated using food web models were compared to No Observed Adverse Effect Level (NOAEL) toxicity reference values (TRVs), considered to be without significant risk of adverse effects to ecological receptors. TRVs were identified from EPA sources, from state regulatory agency sources, and from the toxicological literature. The outcome of all measurement endpoint evaluations is a Hazard Quotient (HQ), which is the ratio of an estimated exposure dose or concentration to a TRV.

With the exception of boron at one location on the beach, no estimated potential HQs exceed 1 and exceed potential HQs for reference areas. The HQ for boron at the one sampling location was 2, which was also essentially equivalent to the background groundwater HQ of 0.7. HQs for other COPECs, including selenium, did not exceed 1 at any other Lake Michigan Beach sample location. Because all HQs associated with potential exposures of piping plovers to COPECs in groundwater at Lake Michigan Beach and in surface water and sediment do not exceed 1 and/or are equivalent to HQs at background areas, these results indicate that conditions in the Lake Michigan Beach

do not pose an unacceptable potential risk to the survival, growth, and reproductive capacity of individual piping plovers.

Removal of the maintenance ash and associated soils in the former staging area and long-term groundwater monitoring were proposed to eliminate source material and document the resulting natural attenuation of the boron and selenium plumes.

CONCLUSIONS

Utilities faced with new federal coal combustion residual (CCR) regulations are required to design and implement groundwater monitoring programs at CCR management structures. The migration of CCR-impacted groundwater to surface water bodies may trigger concerns for facilities sited near surface water bodies. The potential fate and associated risk of CCR impacted groundwater discharging to surface water require a site-specific understanding of the hydrogeologic and geochemical interactions across the interface. Collection of appropriate field data to develop a robust conceptual site model forms the foundation for a robust and defensible risk assessment.

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