Technical Memorandum

PH REQUIREMENTS OF FRESHWATER AQUATIC LIFE

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The pH of surface waters is important to aquatic life because pH affects the ability of fish and other aquatic organisms to regulate basic life-sustaining processes, primarily the exchanges of respiratory gasses and salts with the water in which they live. Failure to adequately regulate these processes can result in numerous sub-lethal effects (e.g., diminished growth rates) and even mortality in cases when ambient pH exceeds the range physiologically tolerated by aquatic organisms.

DIRECT EFFECTS OF PH ON AQUATIC LIFE

The effects of pH on fish and other freshwater aquatic life have been reviewed in detail (e.g., Doudoroff and Katz 1950; McKee and Wolf 1963; EIFAC 1969; Katz 1969; NAS 1972; AFS 1979; Alabaster and Lloyd 1980). The pH of water affects the normal physiological functions of aquatic organisms, including the exchange of ions with the water and respiration. Such important physiological processes operate normally in most aquatic biota under a relatively wide pH range (e.g., 6-9 pH units). There is no definitive pH range within which all freshwater aquatic life is unharmed and outside which adverse impacts occur. Rather, there is a gradual "deterioration" in acceptability as pH values become further removed from the normal range (EIFAC 1969; AFS 1979; Alabaster and Lloyd 1980). The acceptable range of pH to aquatic life, particularly fish, depends on numerous other factors, including prior pH acclimatization, water temperature, dissolved oxygen concentration, and the concentrations and ratios of various cations and anions (McKee and Wolf 1963).

Alabaster and Lloyd (1980) identified the pH range that is not directly lethal to freshwater fish as 5.0-9.0. With few exceptions, pH values between 6.5 and 9.0 are satisfactory, on a long-term basis, for fish and other freshwater aquatic life. The pH of most inland fresh waters containing fish ranges from about 6 to 9 (Ellis 1937), with most waters, particularly those with healthy, diverse, and productive fish and macroinvertebrates communities having a pH between approximately 6.5 and 8.5 units (Ellis 1937; McKee and Wolf 1963; NTAC1968; NAS 1972). In establishing water quality criteria for pH, ORVWSC (1955) stated that, although fish had been found at pH values from 4-10, the safe range was 5-9 and for maximum productivity the pH should be maintained between 6.5 and 8.5. Some aquatic organisms (e.g., certain species of algae) have been found to live at pH 2 and lower, and others at pH 10 and higher (NAS 1972). However, there are few such organisms, and their extreme tolerances are not reflective of the pH tolerated by the majority of organisms occurring in a given aquatic ecosystem.

Limiting pH Values			
Minimum	*Maximum*	*Remarks*	*Reference*
3.3	10.7	Trout survived without adverse effects	1467
3.6	---	Tench survived two weeks but carp died	1302
3.6	10.5	96-hour TL_m range for bluegill sunfish	2934
3.8	10.0	Fish eggs could be hatched, but abnormal young were produced of extreme pH's	1468
4.0	10.0	The most resistant fish can tolerate such extreme pH values indefinitely after acclimatization	1460
4.0	10.1	Limits for the most resistant species	361
4.0	10.4	Limits for bluegill sunfish with HCl and NaOH	3606
4.1	8.5	Range tolerated by speckled trout in nature	1467
4.1	9.5	Range tolerated by trout	862
4.3	---	Carp died in 5 days	1303
4.4	8.7	Toxic limits for trout	3609
4.5	8–9	Trout eggs and larvae develop normally	1636
4.6	9.5	Toxic limits for perch	3609
4.6	---	Tench died in two days	2977
4.8	---	Lower limit for trout	1304
4.8	---	Illness and early death for carp	2977
4.8	9.2	Toxic limits for fish	1305
5.0	---	Toxic limit for sticklebacks	2941
5.0	9.0	Tolerable range for most fish	361, 2409, 3609
---	8.7	Upper limit for good fishing water	717
5.4	---	Lower limit for carp and tench	1306
---	9.2	Upper limit for trout and perch	2977
5.5	---	Lower limit for general fish protection	1307
5.4	11.4	Fish avoided waters beyond these limits	1046
6.0	11.0	Fish did not avoid waters in this range	1046
6.0	7.2	Optimum range for fish eggs	1468
6.5	8.4	Range tolerated by most fresh-water fish	1460
For other aquatic organisms, ranges were reported as follows:			
1.0	---	Mosquito larvae destroyed at this value	1308
2.5	---	Tolerated by *Chlamydomonas, Fragilaria, Asterionella, Aphanizomenon*	2168
3.3	4.7	Mosquito larvae thrived in this range	1309
4.0	---	Toxic for *Paramecium, Volvox, Asplanchna*	2977
7.5	8.4	Good range for plankton production	1021
---	8.5	Algae are destroyed above this value	

Source: McKee and Wolf (1963).

A Summary of Some Effects of pH on Freshwater Fish and Other Aquatic Organisms

pH	Known effects
11.5–12.0....	Some caddis flies (Trichoptera) survive but emergence reduced.
11.0–11.5....	Rapidly lethal to all species of fish.
10.5–11.0....	Rapidly lethal to salmonids. The upper limit is lethal to carp (Cyprinus carpio), goldfish (Carassius auratus), and pike. Lethal to some stoneflies (Plecoptera) and dragonflies (Odonata). Caddis fly emergence reduced.
10.0–10.5....	Withstood by salmonids for short periods but eventually lethal. Exceeds tolerance of bluegills (Lepomis macrochirus) and probably goldfish. Some typical stoneflies and mayflies (Ephemera) survive with reduced emergence.
9.5–10.0....	Lethal to salmonids over a prolonged period of time and no viable fishery for coldwater species. Reduces populations of warmwater fish and may be harmful to development stages. Causes reduced emergence of some stoneflies.
9.0–9.5.....	Likely to be harmful to salmonids and perch (Perca) if present for a considerable length of time and no viable fishery for coldwater species. Reduced populations of warmwater fish. Carp avoid these levels.
8.5–9.0.....	Approaches tolerance limit of some salmonids, whitefish (Coregonus), catfish (Ictaluridae), and perch. Avoided by goldfish. No apparent effects on invertebrates.
8.0–8.5.....	Motility of carp sperm reduced. Partial mortality of burbot (Lota lota) eggs.
7.0–8.0....	Full fish production. No known harmful effects on adult or immature fish, but 7.0 is near low limit for Gammarus reproduction and perhaps for some other crustaceans.
6.5–7.0.....	Not lethal to fish unless heavy metals or cyanides that are more toxic at low pH are present. Generally full fish production, but for fathead minnow (Pimephales promelas), frequency of spawning and number of eggs are somewhat reduced. Invertebrates except crustaceans relatively normal, including common occurrence of mollusks. Microorganisms, algae, and higher plants essentially normal.
6.0–6.5.....	Unlikely to be toxic to fish unless free carbon dioxide is present in excess of 100 ppm. Good aquatic populations with varied species can exist with some exceptions. Reproduction of Gammarus and Daphnia prevented, perhaps other crustaceans. Aquatic plants and microorganisms relatively normal except fungi frequent.
5.5–6.0.....	Eastern brook trout (Salvelinus fontinalis) survive at over pH 5.5. Rainbow trout (Salmo gairdneri) do not occur. In natural situations, small populations of relatively few species of fish can be found. Growth rate of carp reduced. Spawning of fathead minnow significantly reduced. Mollusks rare.
5.0–5.5.....	Very restricted fish populations but not lethal to any fish species unless CO_2 is high (over 25 ppm), or water contains iron salts. May be lethal to eggs and larvae of sensitive fish species. Prevents spawning of fathead minnow. Benthic invertebrates moderately diverse, with certain black flies (Simuliidae), mayflies (Ephemerella), stoneflies, and midges (Chironomidae) present in numbers. Lethal to other invertebrates such as the mayfly. Bacterial species diversity decreased; yeasts and sulfur and iron bacteria (Thiobacillus-Ferrobacillus) common. Algae reasonably diverse and higher plants will grow.
4.5–5.0.....	No viable fishery can be maintained. Likely to be lethal to eggs and fry of salmonids. A salmonid population could not reproduce. Harmful, but not necessarily lethal to carp. Adult brown trout (Salmo trutta) can survive in peat waters. Benthic fauna restricted, mayflies reduced. Lethal to several typical stoneflies. Inhibits emergence of certain caddis fly, stonefly, and midge larvae. Diatoms are dominant algae.
4.0–4.5.....	Fish populations limited; only a few species survive. Perch, some coarse fish, and pike can acclimate to this pH, but only pike reproduce. Lethal to fathead minnow. Some caddis flies and dragonflies found in such habitats; certain midges dominant. Flora restricted.
3.5–4.0.....	Lethal to salmonids and bluegills. Limit of tolerance of pumkinseed (Lepomis gibbosus), perch, pike, and some coarse fish. All flora and fauna severely restricted in number of species. Cattail (Typha) is only common higher plant.
3.0–3.5.....	Unlikely that any fish can survive for more than a few hours. A few kinds of invertebrates such as certain midges and alderflies, and a few species of algae may be found at this pH range and lower

Source: USEPA (1973). Table incorporates information presented by Alabaster and Lloyd (1980).

In response to the acid rain problems occurring in the eastern United States and Canada, the physiological effects of acid stress on fish and other aquatic life have been well documented (e.g., see Alabaster and Lloyd 1980; AFS 1982). A number of researchers have proposed that the toxic action of hydrogen ions on fish under acidic conditions involves production of mucus on the gill epithelium, which interferes with the exchange of respiratory gasses and ions across the gill; precipitation of proteins within the epithelial cells; and/or acidosis of the blood (also affecting oxygen uptake) (Ellis 1937; Westfall 1945; Leivestad, in AFS 1982; Boyd 1990). Hence, respiratory distress and osmotic imbalance are the primary physiological symptoms of acid stress in fish. Less research has been conducted on the effects of acid stress on macroinvertebrates. However, those species that exchange respiratory gasses and regulate ions through their gills (e.g., mayflies and stoneflies) and/or species affected by blood acid-base balance may experience effects similar to fish.

Below a pH of 5.0, mortality occurs in some life stages of certain fish species, although some fishes can be acclimated to pH levels below 4.0. Certain species of macroinvertebrates can tolerate very low pH values. Lackey (1938) found Gammarus spp. in two streams with pH values of 2.2 and 3.2, mosquito larvae in a stream at pH 2.4, and caddis fly larvae (Trichoptera) at pH 2.4. Nevertheless, the primary productivity of freshwater aquatic ecosystems is reduced considerably below pH 5.0, which, in turn, reduces the food supply for higher organisms. Hence, fish that remain present would likely experience reduced numbers and/or growth rates (Alabaster and Lloyd 1980).

The physiological effects on aquatic life induced by high pH (>9) have been studied less than those at low pH. This is likely because high pH waters are less common (Doudoroff and Katz 1950; Alabaster and Lloyd 1980). Several researchers concluded that the toxic mode of action of hydroxyl ions (i.e., high pH values) is hypertrophy of mucus cells at the base of the gill filaments and destruction of gill and skin epithelium, with effects on the eye lens and cornea (Alabaster and Lloyd 1980; Boyd 1990).

Studies have shown that pH values of between 9 and 10 can result in partial mortality for bluegill sunfish (Lepomis macrochirus), rainbow trout (Oncorhynchus mykiss), brown trout (Salmo trutta), salmon, and perch. The majority of freshwater fishes and macroinvertebrates experience harmful effects (lethal or sublethal) at one or more life stages at pH values above 10 (Weibe 1931; AFS 1979; Alabaster and Lloyd 1980). Where high pH is caused by aquatic plant photosynthesis, high water temperatures and supersaturation of dissolved gasses may also occur and may contribute to physiological effects experienced by aquatic organisms, making it difficult to correlate mortality with laboratory data on pH alone. Based on their review of the literature, Alabaster and Lloyd (1980) stated that chronic exposure to pH values above 10 was harmful to all species studied, while salmonids and some other species were harmed at pH values above 9.

The USEPA has concluded that a pH range of 6.5 to 9.0 provides adequate protection for the life of freshwater fish and bottom-dwelling macroinvertebrates. Outside this range, fish suffer adverse physiological effects that increase in severity as the degree of deviation increases until lethal levels are reached (USEPA 1976, 1986).

EFFECTS OF DIURNAL FLUCTUATIONS AND RAPID PH CHANGES ON AQUATIC LIFE

The pH of lakes and streams often changes during the day in response to photosynthetic activity. In ponds having poorly buffered (low alkalinity) waters, the pH may fall to approximately 7 in the early morning and increase to 9 or more in the afternoon (Boyd 1990). Good fish production usually can be maintained in spite of these daily fluctuations. In most lakes and ponds, diurnal pH fluctuations during the summer, when photosynthetic activity peaks, are generally less than 2 pH units, while in streams are generally less (e.g., 0.5-1.0 units). Unless diurnal fluctuations result in ambient pH falling below 6 or being elevated above 9, they generally have no adverse impact on aquatic life. This is supported by the study findings discussed below.

Although it was once believed that fish could not tolerate sudden pH changes, studies conducted by Brown and Jewell (1926) and Wiebe (1931) showed that certain fish species could tolerate such rapid changes, within the normal pH range. Brown and Jewell (1926) observed catfish and perch living in a bog lake having a pH of 4.4-6.4, and also in a nearby glacial lake having a pH of 8.2-8.7. These researchers demonstrated that the fish from both lakes survived transfer from one lake to another.

Wiebe (1931) reported that sunfish (Lepomis spp.) and goldfish (Carassius auratus) survived rapid changes from pH 7.2 to 9.6 (2.4 units); largemouth bass (Micropterus salmoides) from pH 6.1 to 9.6 (3.5 units); and smallmouth bass (Micropterus dolomieui) from pH 6.6 to 9.3 (2.7 units). Witschi and Ziebell (1979) transferred rainbow trout from water of pH 7.2 to waters of pH 8.5, 9.0, 9.5, and 10.0. Survival after 48 hours was 100% for fish transferred to pH 7.2 and 8.5, 88% for those transferred to pH 9.0, 68% for pH 9.5, with complete mortality occurring for fish transferred to pH 10.0. This study clearly demonstrated that rainbow trout could handle rapid pH changes of 1.3 units (from 7.2 to 8.5) without experiencing acute mortality. The acute mortality that occurred when transferred to pH 9.0, 9.5, and 10.0 water was more likely due to being transferred to a pH outside the acceptable range for the species than due to the pH change itself (Modin, pers. comm., 1998). If no acute mortality occurs, no chronic effects would be expected because of physiological acclimation to the new pH, which occurs within a short period of time (i.e., hours to days).

This work demonstrated that the fish species studied tolerated rapid pH changes of 1.3 to 3.5 units when these changes occurred within the physiological-tolerance pH range. When the pH changed to a value that approached the species' normal upper tolerance level (i.e., 9.0) or exceeded their upper tolerance limit (9.5 and 10.0), mortality occurred (Witschi and Ziebell 1979). Based on findings from these studies and personal communications with CDFG fish pathologists (Modin, pers. comm., 1998), it is concluded that neither acute mortality nor chronic sub-lethal effects would be expected in fish experiencing rapid pH changes when all pH levels to which fish are exposed remain within the range of 6.5 to 8.5. Conversely, these studies suggest that small pH changes (e.g., 1 unit) could have adverse impacts when the resulting pH value falls outside the physiologically acceptable range for a given species. For example, rainbow trout acclimated to pH 9.0, which is at or near the species' upper limit, would be expected to experience high mortality if transferred to pH 10.0 and, in fact, would be expected to experience mortality if transferred to pH 9.5 – a change of just 0.5 units (Witschi and Ziebell 1979; Modin, pers. comm., 1998).

The ability of fish to rapidly acclimate to waters having substantially different pH values is further demonstrated by hatchery stocking programs and the freshwater tropical fish (aquarium) industry, where it is common to move fish from one water body or aquarium to another that differ by at least 0.5 pH units, and often by more than 1.0 pH unit. However, it should be noted that this "stocking" of fish typically involves waters with pH values in the range of 6.5 to 8.5 units so that the fish are transferred to waters with pH values well within the range that is physiologically acceptable to them. Available data regarding pH values tolerated by macroinvertebrates suggest that, like fish, they can rapidly adapt to changes in ambient pH levels within their natural pH range (Alabaster and Lloyd 1980; Boyd 1990).

A technical review of the effects of rapid pH changes on benthic macroinvertebrates revealed evidence indicating that macroinvertebrates rapidly exposed to pH changes of one unit or more, when pH is maintained within the 6.5 to 8.5 range, would not experience mortality, or other long-term adverse effects. Information supporting this finding is discussed further below.

The available scientific literature on the effects of rapid pH reductions on benthic macroinvertebrates provides evidence to suggest that rapid pH reductions of one unit or more, when pH is maintained between 6.5 and 8.5, would not cause chronic, adverse effect on individual macroinvertebrates or their populations. A thorough review of the scientific literature was conducted to identify studies that investigated the effects of rapid pH changes on macroinvertebrates, when pH was maintained between 6.5 and 8.5. No such studies were found. The fact that no studies of this nature could be found in the literature further supports the contention that rapid pH changes within the 6.5 to 8.5 range are not problematic to benthic macroinvertebrates. Based on the commonality of their experimental approaches, the acidification studies that are available in the scientific literature suggest that significant adverse effects to individual macroinvertebrates and their communities would not be expected to occur upon experiencing a rapid pH reduction unless the ending pH is below 6.0. Several studies that investigated the effects of stream acidification on benthic macroinvertebrate communities, where ending pH was below 6.0, shed additional light on how a pH gradient within a point source discharge mixing zone would affect benthic macroinvertebrates drifting through the zone; hence, findings from these studies are briefly summarized below.

Bernard et al. (1990) acidified experimental reaches of a British Columbia stream from pH 7.0 to 5.9 within 30 minutes to assess the effect of mild acidification on short-term invertebrate drift. They reported that small Ephemeroptera showed no initial response to pH reductions from 7.0 to 5.9, but that their drift increased after about 6 hours. Increased drift was observed for Chironomid and Trichoptera within an hour of reaching pH 5.9. Harpactacoid copepods, Hydrcarina, simulid Diptera, Plecoptera, and large Ephemeroptera did not respond. Lack of a drift response induced by rapid pH reduction in certain taxa demonstrates that the organisms were not adversely affected enough to move, and consequently, would not be affected enough to experience mortality. Kratz et al. (1994) reported that Simuliids (black flies) did not respond to rapid depressions of 1 pH unit below ambient, with an ending pH of below 6.0. Also, Hall et al. (1987) reported no effect on daytime drift rates in acidic Norris Brook, where pH was reduced from 6.4 to 5.2-5.5. Bernard et al. (1990) surmised that the rapid, large increases in drift exhibited by chironomids were avoidance behavior. Sensitive organisms may escape by drift to more suitable conditions downstream. Bernard (1985) (cited in Bernard et al. 1990) supported this hypothesis by showing that rapidly responding mayflies collected in a stream rapidly acidified to pH 5.7 had greater than 95% survival when subsequently held in circumneutral water for 24 hours. Kratz et al. (1994) concurred with these findings, suggesting that mild pH reductions (i.e., those with an ending pH near 6.0 or above) would likely elicit increased drift in some species due to behavioral responses rather than from causing pH-related mortality, whereas mortality-induced drift would increase as ending pH decreases, and reached lethal levels (e.g., 5.5 or lower).

To determine the direct effects of water chemistry on invertebrates sensitive to pH reductions, Rosemond et al. (1992) transplanted three mayfly species (i.e., *Drunella conestee (*Family Ephemerellidae) and *Stenonema* sp. and *Epeorus pleuralis* (Family Heptageniidae)) from a stream having pH of 6.6-6.8 to: 1) the stream from which they were collected (i.e., back into pH 6.6-6.8), and 2) a stream of pH 5.0 (a rapid pH change of 1.6-1.8 units). In the first *in situ* transplant experiment, there was no significant difference in mortality among the individuals of *Drunella conestee* transplanted into the two sites through 9 days post transplant. Mortality rates were 32% for organisms transplanted back into the same pH, and 28% for those transplanted into pH 5.0. In the second *in situ* experiment, using *Stenonema* sp., and *Epeorus pleuralis*, both species transplanted into the pH 5.0 stream experienced significantly higher mortality that those transplanted back into the original stream. In addition, the ultimate mortality experienced by these two species transplanted into the pH 5.0 stream differed significantly. These researchers concluded that the different sensitivities of the three species was due to differences in sensitivities to ending pH and acquired body burdens of aluminum, rather than to the initially-experienced rapid change in pH. This was supported by the fact that it took 2-6 days for mortality rates to differ between transplant groups for the same species. An inability to tolerate the initial pH shock (an acute phenomenon) would be expected to become apparent within a matter of hours rather than days. This is of particular relevance because macroinvertebrates drifting through a mixing zone would typically pass through the zone in a matter of minutes to hours.

Bell and Nebeker (1969) investigated the tolerance of aquatic insects to low pH. In this study, caddisfly, stonefly, dragonfly, and mayfly nymphs were exposed to a range of pH levels for 96 hours (4 days) to determine the pH levels at which 50% of the test organisms died (96-hr TL_{50}). Field-collected nymphs were acclimated to the laboratory for one week at pH 7.8. However, no gradual acclimation to test pH levels was reported. In fact the methods stated: "*If the test pH deviated by more than 0.25 pH units from the desired pH, the test was terminated*." Hence, test organisms were taken directly from their laboratory acclimation tank (pH 7.8), and placed directly into test tanks maintained at pH 1.0-7.0. The 96-hr TL_{50} values reported for the 10 species tested (from the families identified above) ranged from a low of 1.5 (the caddisfly *Brachycentrus americanus*) to a high of 4.65 (the mayfly *Ephemerella subvaria*) pH units. All 10 species tested showed 100% survival at pH 6.0, a 1.8 unit change from their acclimated pH of 7.8. The mayfly *Ephemerella subvaria* began to experience some mortality at test pH levels below 6.0. However, the caddisfly *Hydropsyche betteni*, stonefly *Acroneuria lycorias*, dragonfly *Boyeria vinosa*, and mayfly *Stenonema rubrum* all showed 100% survival at test pH levels as low as 5.5. Hence, these species showed no mortality when transferred from the acclimation tank at pH 7.8 to test tanks at pH 5.5, thereby experiencing a rapid pH change of 2.3 pH units. The caddisfly *Brachycentrus americanus* showed 100% survival to pH levels of 4.5, thereby experiencing a rapid pH change of 3.3 pH units.

In a follow-up study, Bell (1970) performed similar experiments with the same species of benthic macroinvertebrates, but extended the test period from 96 hours to 30 days. Findings were similar to the 96-hr study, except that the 30-day TL_{50}s were somewhat higher (i.e., higher pH levels) than those reported for the 96-exposure. These studies' findings concur with those of the studies discussed above, indicating that the ending pH is more important in determining mortality than the magnitude and rate of initial pH change.

These studies showed that rapid pH reductions of up to 1.6 pH units, with an ending pH below 6.0, did not cause elevated mortality in mayflies, a taxa of benthic macroinvertebrates shown through numerous studies (e.g., Kratz et al. 1994; Feldman and Connor 1992; Rosemond et al. 1992) to be the most sensitive taxa to pH reductions. Mortality was not shown to occur in sensitive mayfly species, or other macroinvertebrate taxa, when the ending pH was maintained at or above 6.5, as would always occur under compliance with the proposed pH objective.

Personal communications with several macroinvertebrate experts provide evidence in support of the conclusions pertaining to rapid pH changes stated above. S. Cooper (U.C. Santa Barbra, pers. comm., 1999), R. Haro (U.W. LaCrosse, pers. comm., 1999), and J. Harrington (CDFG, pers. comm., 1999) all concurred that the lack of studies in the scientific literature addressing pH changes within the 6.5 to 8.5 range suggest that rapid changes within this range are unlikely to adversely affect macroinvertebrates. Moreover, none of these experts were aware of any studies reported in the literature that document mortality to macroinvertebrates resulting from rapid pH changes with in the 6.5 to 8.5 range.

When asked to give their professional opinion regarding potential effects of rapid pH changes on benthic macroinvertebrates within the context of what can occur across the mixing zone associated with a municipal effluent discharge, the following statements were made.

A pH change from 8.5 to 7.0 would not be expected to have a lethal effect, but could have a sublethal (e.g., behavioral) effect. Nevertheless, sublethal effects would be expected to cease when the macroinvertebrates acclimated to the new pH. One would not expect to see lethal effects until the ending pH fell outside the normal pH range, perhaps 5.5 or 5.0 pH units (Cooper, pers. comm., 1999). S. Cooper is considered to be the leading expert on the West Coast regarding the effects of acid pulses on stream benthic macroinvertebrates.

As long as pH remained within the 6.5 to 8.5 range (referred to as circumneutral), there generally would not be any substantial adverse effects to macroinvertebrates drifting downstream into the effluent-dominated portion of the creek, where pH could be 1-2 units lower. Short-term sublethal (e.g., behavioral) effects could occur in some species (Haro, pers. comm., 1999).

In discussions with Jim Harrington of CDFG, regarding ranges of pH acceptable to aquatic life, he stated the following, *"The pH range of 6.5 to 8.5 is accepted to represent safe levels, and this is probably why there is not much literature on its effects to the aquatic system. When I write biological significance reports on pH-related spill events, I would conclude that there would be no deleterious effects within this range."* (Harrington, pers. comm., 1999).

The USEPA's past and current national pH criteria for the protection of aquatic life provide evidence to suggest that rapid pH changes, when pH is maintained within the 6.5 to 8.5 range, would not cause adverse impacts to benthic macroinvertebrates or their communities. Based on the language used by the NAS in its 1972 criteria referring to pH changes above or below the "…natural seasonal", it is clear that the 0.5 unit of change allowed under the "nearly maximum level of protection" was defined to limit the ambient pH range, not the magnitude of rapid change within this range. In fact, no quantitative criterion was assigned to limit rapid pH changes within the preferred pH range of 6.5 to 8.5. Similarly, the USEPA's current pH criterion for the protection of freshwater aquatic life (USEPA 1986, 1999a) simply defines an acceptable ambient pH range (i.e., 6.5-9.0), but does not quantitatively limit the magnitude of rapid change that organisms can be exposed to within this range (e.g., during movement through mixing zones associated with point-source discharges). Because the magnitude of rapid change to which freshwater aquatic life are exposed, within acceptable ambient pH ranges, has never been regulated as part of any national pH criterion, it can be reasonably concluded that all available scientific data on this issue indicate that the effects of rapid pH changes are insignificant when pH is maintained within the acceptable ambient range (e.g., 6.5-8.5).

Based on the above discussion, the proposed pH amendment is strongly supported by the current science regarding pH requirements of freshwater aquatic life and would be consistent with, but somewhat more restrictive than, USEPA's current national recommended criteria for the protection of freshwater aquatic life.

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