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Analysis of Freshwater Mussel Stresses: Stress Effects, Sources, and Mitigation

With Emphasis on the Horse Lick Creek, Kentucky, site

Jackie E. Mohan
Southern Heritage Task Force
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I. STRESSES

A. **Siltation**, or fine-grained sedimentation

1. Changes in substrate

a. Blanketing effect on the substrate

i. mussels, especially Cumberlandian species, require stable, silt-free rubble, gravel, and sand shoals (USFW, 1984)

b. Silt can cement substrate together, inhibiting mussels from burrowing (Layzer and Anderson, 1992)

c. After parasitizing host fish, juvenile mussel will be smothered if it drops onto silt-laden substrate (Stein, 1971)

d. Adult mussels cannot survive in silt levels greater than 6 mm (Layzer and Anderson, 1992; USFW, 1984; Ellis, 1936)

e. One (1) foot below the surface of fine organic sediment, the dissolved oxygen is only 6% of that in the stream above (Fuller, 1974)

f. Impacts on host-fish populations

i. smothers fish eggs and larvae

ii. reduces food availability

iii. fills interstitial spaces in substrate

- eliminates spawning beds
- eliminates habitat critical for young fish

(USFW, 1984; Loar et al., 1980)

iv. in a study of two east-central Kentucky streams, the authors discovered that reproduction in darters was reduced by siltation via prevention of mating or mortality of fry and eggs (Branson and Batch, 1972)

- two species of insectivorous darters (greenside darter and emerald darter) have been identified as the host fish for the endangered *Pegias fabula*

- several darter species within the subgenous *Cantonotus* have been recognized as the host fish for the endangered *Villosa trabalis*

(Layzer and Anderson, unpublished data; as reported in Layzer and Anderson, 1992)

2. High turbidity levels in water column

   a. Abrasive effect on gills and feeding structures

      i. irritate
      ii. damage
      iii. impede => smothering and/or starvation

      (USFW, 1984; Loar et al., 1980)

   b. Competition with nutritional elements in filter feeding organisms

      i. causing

         * nutritional stress
         * mortality

         (Loosanoff, 1961; USFW, 1984; Dennis, 1989)

      ii. some investigators feel that the primary mechanism through which silt acts is the dilution of the food source (Dennis, 1984)

         * In this case, a more important measure than simple silt concentration would be the ratio of organic (food) particles to inorganic (non-food) particles

   c. Reduced light penetration (USFW, 1984)

      1. especially when coupled with eutrophication, causes respiration rate to exceed rate of photosynthesis => decreased dissolved oxygen

2. decreases the intensity of mussels' phototactic responses (Ellis, 1936)

   a. mussels normally move away from bright light, possibly to avoid water that is too shallow

      i. avoids dessication
      ii. avoids predaton

      (Fuller, 1974)

   b. this reponse would be impared in water with high turbidity levels

3. decreases production of mussels' nutritional elements (Fuller, 1974)

d. Causes mussels to remain closed (thus imparing the filter feeding system) almost 50% longer than in low turbidity water (Fuller, 1974)

3. Siltation has been shown to retard the growth of *Amblema plicata* (Stansbery, 1970; Fuller, 1974)

4. Siltation seems to enhance bacterial attack of glochidia in the marsupian (Ellis, 1931)

5. As a result of increased siltation, investigators observed a 90% decrease in total benthic population size and number of species (Branson and Batch, 1972)

6. Powell River example

   a. "Heavy deposition of silt from abandoned strip mines resulted in obliteration of all benthic organisms in the uppermost reaches of the river...the diversity and abundance of benthic organisms increased as the degree of siltation became less, until, at the lowermost reaches, a rich and diverse benthic fauna including freshwater mussels was observed" (Dennis, 1984)

7. Other studies indicate

   a. low concentrations of silt that has organic particles adsorbed to it does NOT harm mussels, as does silt when added alone (Jorgensen, 1975; Arruda et al., 1983)

   b. the organic:inorganic ratio is probably important

c. other investigators have actually observed increases in mussel food uptake upon adding low concentrations of silt (12.5 mg/L and 29 - 119 mg/L, respectively) to aqueous medium (Winter, 1975; Dennis, 1984)

8. Unfortunately, not enough thorough, species-specific <u>quantitative</u> work has been done on the effect(s) of silt on freshwater mussels. It is impossible to generate any species silt threshold limits, or to say, for example, that species X can tolerate up to Y amount of deposition and Z amount of turbidity, etc.

B. Pollution

1. Bioaccumulating materials

   a. Because mussels are filter feeders, these pollutants accumulate <u>in vivo</u> in much higher concentrations than in the water

   b. Types

      1. Organic compounds

         a. *Elliptio complanata* concentrated diazinon and parathion in levels greater than the concentrations in surrounding water; the compounds were metabolized very slowly (Miller et al., 1966)

         b. when dieldrin concentrations existed at *20 ppt* in the water column, *Amblema plicata* concentrated the compound at levels about <u>2500 greater</u> than background levels (Fikes and Tubb, 1971)

         c. *Lampsilis radiata luteola* and *Anodonta grandis* were termed "excellent monitors" of chlorinated hydrocarbons, including DDT, aldrin, and methoxychlor; it was believed that one or more of these compounds caused the observed deaths (Bedford et al., 1971; Fuller, 1974)

d. unexpectedly low concentrations of the organochlorine pesticides DDT, DDE, heptachlor epoxide, and dieldrin were found in mussels under study (Starrett, 1971). The author advanced two possible reasons for the low *in vivo* concentrations

i. a change in agriculture from organochlorine pesticides to organophosphate pesticides

ii. the adsorption of the compounds to substrate particles

2. Heavy metals

a. COPPER

i. exposure to *25 ppb* of copper for several months was lethal to certain (unspecified) mussels (Imlay 1971)

ii. along with MERCURY and SILVER, considered to be the most toxic metal to mussels (Wurtz, 1962)

b. ZINC

i. zinc concentrations averaging *65 ppm* believed to have played a role in the extermination of mussels in portions of the Nolichucky River in Tennessee (Mullican et al., 1960)

ii. one of the most lethal metal to freshwater mussels (Wurtz, 1962)

2. Nitrogen-ammonia

a. In Illinois River, no mussels occurred in upper section where NH_3 concentration was *greater than 6.0 ppm*. However, mussels reappeared in lower stretches where the NH_3 concentration was at or below the 6.0 ppm level. Four species of fish did occur in the sections devoid of mussels (Starret, 1971); three of these fish species were later shown to be glochidia hosts. It is assumed the NH_3 had some effect on the mussels themselves (Fuller, 1974).

3. Organic enrichment

   a. small amounts of organic enrichment (no quantitative data) actually seem to benefit mussels

      1. increased production of food sources (van der Schalie, 1938; Fuller, 1974)

      2. unusually high mussel densities have been found downstream of areas rich in decaying vegetation (Churchill and Lewis, 1924)

      3. healthy, unusually dense mussel populations were found in water containing trace amounts of sewage runoff (Coker et al., 1921)

   b. above some threshold level (possibly species-specific), organic enrichment is detrimental to mussels (again, a lack of quantitative data)

      1. increased growth of submerged vegetation

         a. alters substrate profile

         b. trap for silt

         c. slows current

            i. increased bacterial oxygen demand (BOD)

            ii. increased CO2 concentration

            iii. lowered pH

            (Grantham, 1969; Fuller, 1974)

         d. above conditions are "inimical to the great majority of mussels" (Fuller, 1974)

      2. total extirpation of mussels caused by sewage in parts of the Kankakee River,

Indiana, and Salt Fork of the Vermillion River, Illinois (Wilson and Clark, 1914; Baker, 1922; Fuller, 1974)

c. may contain toxic compounds

1. mussels severly restricted in Ottawa River by wastes from slaughter house (Fuller, 1974)

C. **Physical destruction**

1. Sedentary organisms like mussels very susceptible to localized destructive impacts like crushing

2. Destruction of stream riffles devastates present and future mussel habitat

D. **Altered water temperature**

1. Temperature tolerances vary from species to species; not a lot of species-specific tolerance work has been done (Fuller, 1974)

2. The endangered <u>Pegias fabula</u> inhabits cool water (USFW, 1989)

3. The maturation of some Lampsilinae is delayed in the deeper, cooler waters of western Lake Erie (Stansbery, 1967)

4. Low temperatures (not quantitatively defined) result in a low rate of glochidial parasitization of host fish (Arey, 1921; Fuller, 1974)

5. Oxygen consumption has a *positive* correlation with temperature (Fuller, 1974); oxygen concentration in water has a *negative* correlation with temperature

6. A digestive enzyme in *Elliptio complanata* has an optimal activity level at 10°C (Hobden, 1970)

7. Sperm release is stimulated in *Anodontoides ferussacianus* by a sudden temperature change from 27°C to 22°C (Edgar, 1965)

8. Egg mass discharge is stimulated by a sudden decrease in temperature (Matteson, 1955; Fuller, 1974)

9. Consider host fishes' temperature requirements

10. Due to lack of information regarding the temperature requirements of each species, should avoid any non-historical fluctuations in temperature

    a. Horse Lick Creek presently a trout (cool water) stream

    b. should therefore especially avoid any impacts that would increase the stream temperature

E. **Reduced dissolved oxygen (DO)**

1. Adult and juvenile subjects of several riffle mussel species required 2.5 ppm of DO for survival at summer temperatures in lab (DO is at the lowest level *in situ* during summer months) (Imlay, 1971)

2. All the above riffle species required 6 ppm of DO for normal growth (Imlay, 1971)

3. Grantham (1969) found no living mussels in sites where DO occassionally dropped to 3 mg/l

4. Pool species of mussels (as oppossed to the river/riffle type found in HLC) can survive in lower DO concentrations (Fuller, 1974; Imlay, 1971)

5. Large-bodied mussel species have lower metabolic rates, therefore lower DO requirements and increased tolerance to hypoxial conditions (Fuller, 1974). Conversely, *smaller-bodied mussels have higher metabolic rate and a higher DO requirement*

    a. implications for the tiny, endangered Pegias fabula

F. **Water pH and hardness change**

1. Prefer/require supraneutral pH with adequate concentrations of bivalent cation (Ca^{2+}, Mg^{2+}) compounds needed for shell formation (Grantham, 1969; Fuller, 1974; Layzer and Anderson, 1992)

2. Soft, poorly buffered water can be subject to rapid pH changes which are harmful to mussels (Fuller,

1974)

3. Decreasing the pH of the water can have a <u>lethal effect</u> (Matteson, 1955)

   a. When the pH of water is lowered, the concentration of CO2 increases to the point that it may interfere with the gas exchange of the mussel (Grantham, 1969; Fuller, 1974)

   b. Many enzymes and their implied physiological functions have an optimal pH in the basic range (Hobden 1970)

   c. Acid can eat holes through the mussel shell to the body (Fuller, 1974; Simpson, 1899)

   d. Alkaline waters precipitate out metals as harmless hydrates; acidic waters bring metals into solution (Fuller, 1974; Wurtz, 1962)

4. Sites where macroinvertebrate life has been practically exterminated due to acid mine wastes have been recorded for portions of the Cumberland River as much as 80 years ago (Wilson and Clark, 1914; Stansbery, 1969; Fuller, 1974)

G. **Supranormal competition for food and space**

1. Normal competition for food and space are very important forces in shaping the population dynamics of a species

2. Extra competition results in increased mortality of less fit individuals

   a. when this competition is increased suddenly (for example, upon the introduction of an exotic species) and is with a different species possessing a higher fitness value, the original, less fit species will likely be extirpated or severly reduced in numbers in the short-term and totally extirpated in the long-term

   b. grave implications when the original population is one of the few remaining populations of its kind

H. **Loss of population size/viability**

1. In order to remain environmentally, demographically, and genetically viable, a population must be of sufficient size.

2. When the rates of mortality and efflux exceed the rates of birth and influx, a population declines in numbers; if the mortality and efflux rates are great enough/birth and influx rates low enough, or if this situation occurs for a long enough time, extirpation of the species will result

3. Several small, isolated populations can not be substituted for one large one; the individuals must be in close enough proximity to interbreed.

   a. although freely discharged sperm may be carried by the current for some distance downstream, there is no certainty that this distance is very great

4. Of the seven (7) known populations of *Pegias fabula* the Horse Lick Creek population is one of the two largest. It is in additon the healthiest known *Pegias fabula* population (USFW, 1989; Layzer and Anderson, 1992)

5. The endangered *Villosa trabalis* apparently inhabits only eight streams; one of them being Horse Lick Creek (Layzer and Anderson, 1992). It is vital that its population not be further reduced by any negative impacts along this stream.

6. The Cumberland River system contains one of the two largest populations of riverine unionid species in the world (Johnson, 1980; USFW, 1989)

II. SOURCES

A. Siltation

1. Reduction in water flow resulting from barrier action of dams (USFW, 1984)

2. Mine runoff (Matter and Ney, 1981; USFW, 1984, 1989; Wolcott, 1990; Layzer, 1992)

3. Road construction and lack of maintenance (Douglass and Swank, 1975; Patric, 1976; USFW, 1989,1984)

4. Off-road vehicle (ORV) use (Johnson and Smith, 1983)

5. Stream crossing practices and structures

6. Agricultural runoff (Meade, 1969; Fuller, 1977; USFW, 1984)

7. Forestry activities and runoff (Patric, 1976; Fuller, 1977; USFW, 1984)

B. **Pollution**

1. Organic compounds

a. Pesticides, herbicides
i. agriculture
ii. forestry

b. Urban and industrial runoff

2. Heavy metals (USFW, 1989)

a. Mine runoff
b. Urban runoff

C. **Physical destruction**

1. Dredging (USFW, 1988, 1984)
2. Poor stream crossing practices of recreational off-road vehicles (ORV), forestry and agricultural

D. Alteration of **water temperature**

1. Cutting or other destruction of streamside vegetation and canopy (Budd *et al.*, 1987)

2. Silt stratification in slow-moving water interferes with heat transmission and produces a lag in both the warming and cooling of the water (Ellis, 1936)

E. Reduction of **dissolved oxygen** (DO)

1. <u>eutrophication</u> from N and P

a. usually from runoff

i. domestic
ii. agricultural
iii. forestry

b. increases biological oxygen demand (BOD)

i. reduced available oxygen (Grantham, 1969; Fuller, 1974)

c. increases CO_2 concentration, which interferes with mussels' gas exchange (Grantham, 1969; Fuller, 1974)

2. reduced water flow

a. dams, impoundments, reservoirs
b. submerged vegetation (Grantham, 1969; Fuller, 1974)
c. especially harmful to riffle mussel species, such as those in Horse Lick Creek (Fuller, 1974)

F. Water **pH and hardness** change

1. acidic mine runoff (Wolcott, 1990)

2. excess organic enrichment (eutrophication) lowers the pH of water (Grantham, 1969; Fuller, 1974)

G. Supranormal **competition for food and space**

1. Exotic species

a. *Corbicula* (Asian clam)

i. competitor for space (Fuller, 1974)

ii. may have been chief cause of reduction or extinction of some native mussels in the eastern Gulf drainage (USFW, 1988)

iii. already occurs in Horse Lick Creek (DiStefano, 1984)

b. Zebra mussels

2. Invasive native species

H. Direct loss of **population size/viability**

1. Overharvesting of shell material

2. Over-predation

a. muskrats (Neves and Odom, 1989)

III. MITIGATION

A. **Impoundments, dams, and dredging**

1. The initial dredging associated with water impoundment directly destroys the mussels, their on-site habitat, and increases the sediment load in downstream water

2. Reduction in water flow causes

   a. increased water depth

      i. decreased dissolved oxygen

      ii. increased carbon dioxide

      iii. increased carbonic acid

      iv. decreased light levels

   b. increased stream bed depth

      i. increased silt layer

      ii. increased organic particular deposition

      iii. altered substrate texture

   (Stansberry, 1973; Horne and McIntosh, 1979

3. Since the impounding of much of the Mussel Shoals in the Tennessee River, 30 mussel species have been extirpated (Stansbury, 1964)

4. The Cumberlandian species are especially susceptible to negative impacts from impounding (Stansbury, 1964)

5. As would be expected, shallow-water species (such as those found in HLC) are almost totally wiped out as a result of the increased silt level on the substrate and the increased water depth that occurs after damming (Stansbery, 1964)

6. The endangered *Villosa trabalis* has already been extirpated from several Cumberlandian streams as a result of impoundment (Layzer and Anderson, 1992)

7. The literature suggests no mitigation measure exists for the vastly increased siltation and water level that occurs with impoundment; it is therefore suggested that <u>no impoundment</u> take place on Horse Lick Creek or on any of its tributaries that contain mussel populations

B. Strip mining operations

1. Silt, sediment, heavy metals, and chemicals move from mined areas to surface waters (SCS, 1978; Wolcott, 1990)

2. Water pollution from mined site may affect locations many miles away (SCS, 1978)

3. The mussel populations have been extirpated in many streams of the Cumberland River System that receive coal mine drainage (Wolcott, 1990; Layzer and Anderson, 1992)

4. In a seventeen (17) month study of the effects of strip mining on the fauna of two east-central Kentucky streams, the investigators found that benthic food organisms were reduced by at least 90% (Branson and Batch, 1972)

5. In another study of Cumberland streams, <u>including</u> Horse Lick Creek, the investigators concluded:

> Mussel populations, including endangered and status species, have been devastated in these streams. The distribution of mussels and water quality in these streams was clearly related to mining activities (Layzer and Anderson, 1992).

6. Studies by USDI (1967) signify the primary cause of sedimentation from mined land is inadequate vegetation cover (reported by SCS, 1978)

   a. natural regeneration usually results in indigenous tree seedlings that take 8-10 years to serve as effective erosion control measures <u>particularly</u> on the steep terrain of the Appalachian Mountains (Ruffner, 1978)

   b. the planting of sod grass is a very effective erosion control practice (Dunne and Leopold, 1978; HDI, 1991 as reported in Harding and Fifield, unpublished); native grass species are generally less effective as erosion control devices (Harding and Fifield, unpublished).

c. It is suggested that the grass species be amendable to the regeneration of trees and other woody plants: A <u>mature</u> forest is one of the most effective erosion control measures (Erman *et al.*, 1977; Dunne and Leopold, 1978; Palfrey and Bradley, 1982; Harding and Fifield, unpublished)

7. Riparian forests significantly reduce the sulfate concentration in subsurface waters (Lowrance et al., 1984)

   a. use of forested streamside buffers to mitigate acidic mine runoff

8. In a 5 year study, grassed streamside buffers removed <u>all</u> copper from surface and subsurface flow (Groffman et al., 1990)

9. Matter and Ney (1981) discovered that even on vegetatively reclaimed mines, the water quality and aquatic fauna may be significantly indistinguishable from abandoned mines for at least 4-7 years following reclamation:

   a. aquatic biota and water quality compared for two streams in southwestern Virginia reclaimed (graded & seeded) 4-7 years ago with

      i. streams draining unreclaimed, abandoned contour strip mine land

      ii. unimpacted stream

   b. results were the *reclaimed* streams, as compared to the *unimpacted stream control*, exhibited

      i. <u>significantly higher</u>

         * alkalinity
         * hardness
         * sulfate concentration
         * inorganic particle density
         * mean suspended solids
         * benthic sediment

      ii. <u>significantly lower</u>

* benthic invertebrate abundance
* fish abundance
* fish density
* pH
* stream discharge

c. the authors found the results of the *reclaimed streams* similar to those found in the literature for streams draining *unreclaimed, abandoned* mine lands

d. a very important finding was that even the **initiation** of the aquatic restoration process was <u>not</u> detected

e. <u>conclusions</u>

i. "Haul roads continued to carry vehicular traffic after reclamation and supported little vegetation in the areas adjacent to the mining-impacted streams. These bare areas were probably major contributors to stream sediment loading, and will continue to be if such access points are not permanently closed to travel and revegetated."

ii. "Continued sedimentation from mined areas and haul roads affected stream habitat and appeared to be the major factor limiting biotic recovery."

iii. **"Terrestrial reclamation does not assure lotic restoration"**

10. Layzer and Anderson (1992), in their study of Horse Lick Creek

a. observed:

i. metal concentration increased downstream of mine drainage, while mussel populations decreased

ii. in every case, the decline of mussels coincided with the occurrence of mine drainage

b. concluded:

i. "Only a total moratorium on mining within watersheds containing endangered species can prevent the extinction of these species"

C. **Road construction and maintenance**

1. Background

   a. Poor road condition and use have been listed as some of the primary causes of sedimentaton from such activities as

      i. forestry
      (Douglass and Swank, 1975; Patric, 1976; WSFPTAC, 1979; Megahan, 1980)

      ii. mining
      (Matter and Ney, 1981)

   b. When not properly constructed, roads serve as giant gullies through which water is channeled, thus increasing the erosion rate (NCDFR, 1989)

2. Construct roads along contours (NCDFR, 1989)

   a. greatly diminished the gravitic downstream channelization of water

3. Construct roads at least one (1) year before use to allow some stabilization and revegetation (NCDFR, 1989)

4. Preferentially place roads on gentle side slopes rather than on ridge tops (NCDFR, 1989)

5. Avoid floodplain and other poorly drained soils (NCDFR, 1989)

6. Maintain a 100' buffer on either side of perennial and intermittent streams on which no roads or trail are constructed (NCDFR, 1989)

7. On soils with severe erosion hazard (such as most of the soil of HLC watershed), road grades should be 8% or less. Road erosion will be greatly reduced if the road grade is changed frequently, rather than maintaining long, continuous gradients (NCDFR, 1989).

8. On highly travelled areas and steep slopes use gravel or crushed stone to

   a. cover ground

      i. stabilize surface

      ii. reduce rainfall impact

   b. filter sediment

9. On the road surface and along banks, use

   a. **sediment traps**

      i. check dams - "a small dam constructed in a gully [such as a road] or other small watercourse to decrease the stream flow velocity, minimize channel scour, and promote deposition of sediment. It creates a miniature sediment basin" (NCDFR, 1989)

      ii. silt fences

      iii. require continuous maintenance, excess sediment decreases efficiency

   b.. **sediment barriers**

      i. hay bales

         - perimeter filter along bank

      ii. water bar - "a diversion ditch and/or hump across a trail or road tied into the uphill side for the purpose of carrying storm water runoff into the vegetation, forest floor, ditch, or dispersion area so it does not gain the volume and velocity which causes soil movement and erosion" (NCDFR, 1989)

         - can be used in conjunction with grassed waterways which conduct the diverted surface water to the desired area (ie, undisturbed stream buffer)

10. To provide good road drainage, use

a. rolling, or broad-based, dip - "a shallow depression built diagonally across a road or trail designed to remove storm water from the road or trail" (NCDFR, 1989)

i. broad based drainage dips

- provides cross drainage on flat and insloped haul to prevent buildup of excessive surface runoff and subsequent erosion; *usually not used on steep slopes or skid trails*

Spacing (ft.) = (400′ / Slope %) + 100′

Only used on road grades up to 12%
(NCDFR, 1989)

ii. rolling dip

- rounded hump and reverse slope that are not damaged by tree dragging (as would be broad based dips); *can be used on heavily used primary skid trails and on slopes over 12%*

Grade of Skid Trail (Percent)	Distance Between Rolling Dips (Feet)
5 - 10	150
11 - 15	135
16+	120

- place heavy brush, riprap, or other erosion control material below the outlet of dip to serve as an energy absorber where potential for gullying exists
(NCDFR, 1989)

b. culverts - pipes through which surface water can flow under the road

11. vegetated filter strips

a. strips of vegetation along roads to act as filters for sediment eroding from road surface

b. consider removing shading overstory vegetation to aid the drying of the roadbed (NCDFR, 1989)

i. be sure adequate ground cover exists

ii. seed and mulch if adequate groundcover not present

12. Seed & mulch roads and banks as quickly as possible

i. provides vegetated cover which is the most effective means of erosion and sediment yield control

ii. use grass species that will allow the eventual regeneration of woody species

- mature trees are even better than sod at controlling erosion

13. Restrict traffic on roads when soil moisture content is high (NCDFR, 1989; something else ...)

14. Keep roads and trails free from ruts and obstructions (NCDFR, 1989)

15. Keep drainage systems functioning after storm events by removing sediment and debris

D. Off-road vehicle (ORV) use

1. Moderate-heavy ORV use on slopes averaging 36-44% caused an soil loss rate of 300-600 tons/acre/year.

2. Soil loss on upper slope segments was seven (7) times that of segments on lower slopes (Johnson and Smith, 1983)

3. Contribute to the physical destruction of mussel beds by not using provided stream crossing measures (eg, bridges)

4. Recommend

a. limiting access to site by using gates, boulders, logs, etc. to block trails and roads used by ORV

b. especially concentrate on decreasing visits to sites on upper slopes

E. Stream crossings

1. Three main types

   a. pipe culverts

   b. fords

   c. bridges

2. Keep the number of stream crossings to a minimum

3. All stream crossings should be made at right angels to the stream

4. All road and trail approaches to streams must have good surface drainage

   a. should provide mechanism (such as ditch turnouts) for water to be transported onto undisturbed areas, upslope and away from stream crossing

   b. where turnouts cannot be used, utilize other methods like riprap ditch liners, check dams, grass and mulch, etc.

   (NCDFR, 1989)

5. All bare ground near streams should be stabilized as soon as possible. This includes road surfaces (NCDFR, 1989)

6. Pipe culverts

   a. involves putting one large or several small pipes ("culverts") on a grade on the stream bed; the pipe(s) allow the flow of water, the remainder of the stream crossing area being filled in (NCDFR, 1989)

   b. this method is NOT recommended for aquatically significant sites like Horse Lick Creek

i. it is probable that the altered water flow and pipe structures would significantly impact the dispersal of mobile organisms (like the host fish of HLC's mussel species)

ii. any mussel beds on the stream crossing site would be buried and destroyed

iii. the sediment load of the stream may be increased through the water-fill interface

7. Fords

a. "Fords are 'Minimum use' crossings where the stream has an existing or applied firm base. To avoid unacceptable impacts, apply adequate riprap stone, a layer of poles (corduroy) or other effective material to crossings to stabilize road or trail, banks or stream channel. Poles used in fords should be used after use" (NCDFR, 1989).

8. Bridges

a. construct to handle the maximum flow

b. protect stream channel and banks from erosion during the site clearing and bridge construction

c. install sufficient abutments and headwalls to handle high flow conditions and help stabilize the stream crossing area

d. revegetate and stabilize all bare areas as soon as possible

(NCDFR, 1989)

F. Agricultural runoff

1. Causes levels of the following to be increasd in the stream

a. silt

b. chemical pollutants

i. eutrophying fertilizers

ii. toxic pesticides & herbicides

2. Especially harmful when done on sloped land with highly erodible soils (such as Horse Lick Creek)

   a. chemical pollutants transorted by being

      i. dissolved in water

      ii. adsorbed to silt particles

   b. water erosion rate proportional to

      i. slope steepness

      ii. soil erodibility

   (Dunne and Leopold, 1978; Fifield and Harding, unpublished)

3. Crop production

   a. field with a high percentage of bare ground, such as row crops like tobacco, expected to have a higher rate of sedimentation and pollutant transport

      i. erosion rate inversely proportional to the amount of uncovered ground (Dunne and Leopold, 1978; Fifield and Harding, unpublished)

   b. follow Jackson County Soil Conservation Service recommendations and not allow crops production or animal pasturing on any sites classified as having a "severe" or "moderate" erosion hazard; in Jackson County, soils on slopes over 2% are susceptible to excessive erosion if cultivated (SCS, 1989)

   c. while and where crop production is occurring, utilize the following mitigation measures

      i. contour tillage (Dunne and Leoplold, 1978; SCS, 1989)

      ii. terracing (Dunne and Leopold, 1978; SCS, 1989)

      iii. contour stripcropping (SCS, 1989)

      iv. crop rotation of grasses and legumes (SCS, 1989)

v. diversions & vegetated waterways (SCS, 1989)

vi. using crop residue, green manure crops, & cover crops (Dunne and Leopold, 1978; SCS, 1989)

* *mulching* was determined to be the most effective measure to reduce soil erosion and increase water infiltration (Leopold and Maddock, 1954)

vii. utilize a vegetated stream buffer of at least 100′ to decrease the stream load of pollutants (chemical and silt)

* for dissolved chemicals & nutrients, the most important factor affecting the effectiveness of the buffer is the <u>buffer width</u> (Phillips, 1989

4. Animal grazing

a. soil loss is directly proportional to the density of animals grazing the site via

i. soil compaction

ii. loss of vegetative cover

(Dunne and Leopold, 1978)

b. soil loss can be minimized by controlling the number of animals allowed to graze on it (Dunne and Leopold, 1978; SCS, 1989) and by rotating the grazed areas

c. in one study, the combination of steep slopes, heavy rains, and erodible soils caused active gullying to take place even after the initial stimulus of sheep grazing was removed (Dunne and Leopold, 1978)

d. follow the SCS recommnedations regarding the carrying capasity of these soils (SCS, 1989)

e. as stated above, the rate of erosion is proportional to the slope steepness and soil erodibility

i. do not allow grazing on any site

with "severe" or "moderate" erosion hazard, or on any other land not recommended for this purpose by the SCS (SCS, 1989)

5. Streamside buffer strip

a. strip of undisturbed vegetation on either side of perennial and intermittent streams

b. serves to filter sediment (Dillaha et al., 1985; Magette et al., 1987)

i. grass filter strip 150′ wide on a 3% slope reduced sediment by 90%

* the steeper the slope, the wider the strip should be

* on slopes > 10%, the "strip" should be treated as a "buffer" {ie, left undisturbed}

(Palfrey et al., 1982)

c. vegetation utilizes nutrients from runoff, aiding in a removal from the stream load

i. some questions exist as to how long and how well buffer strips remove the high concentration of nutrients in agricultural runoff (Omernik et al., 1981; Dillaha et al., 1985; Magette et al., 1987; Magette et al., 1989)

ii. other investigators conclude that significant amounts of nitrate is denitrified in the buffer strip, not taken up by vegetation (Jacobs, 1985)

iii. studies of subsurface flow indicate riparian forests are sinks for nitrate, calcium, magnesium, potassium, and sulfate (Lowrance et al., 1984)

iv. in one study, the uptake and removal by riparian forests prevented agricultural nutrients from reaching streams

* authors suggest periodic harvest of

trees in order to maintain continual uptake of nutrients (Lowrance et al., 1983)

v. in North Carolina study, riparian zones required 15-80 m widths (depending on site-specific conditions) to filter nitrogen from agricultural runoff (Phillips, 1989)

G. **Forestry activities**

1. Erosion

a. In eastern forests the infiltration rate typically exceeds the rate of rainfall; thus surface runoff is probably not a factor except for the most severe storm events, and water erosion is minimal in <u>undisturbed</u> eastern forests (Lull, 1965; Fifield and Harding, 1992)

b. Erosion associated with road use and construction is probably the most pervasive erosive activity of forestry operations (Douglass and Swank, 1975; Patric, 1976; WSFPTAC, 1979; Megahan, 1980)

c. Logging activities also increases the rate of erosion and the frequency of erosive events (Ziemer et al. 1991; Megahan, 1980)

i. when the forest floor is disturbed, the erosion rate can potentially increase greatly above the historical level (Patric, 1976; Dunne and Leopold, 1978; Zeimer et al., 1991; Fifield and Harding, 1992; S. Boyce, oral communication)

* **The undisturbed forest floor is probably the most effective erosion prevention measure** (Zon, 1927; Patric, 1976; Fifield and Harding, 1992)

ii. in a Coweeta, NC, study, it was shown that

* the baseflow seston (organic particulate) concentration in streams draining logged areas may return to

normal (unlogged) levels within a few years

* however, the seston concentration during storm events may be elevated for many years

(Golladay *et al.*, 1987)

iii. loading decks greatly compress the soil causing the area to have a high erosion potential (Fifield and Harding, 1992)

iv. channels result from the dragging (skidding) of logs and the ruts caused by heavy equipment use

v. site prep activities can cause tremendous increase in the erosion rate

* equipment usage
    - disturbs soil
    - destroys forest floor

* burns
    - increases amount of silt and ash
    - destroys the protective floor cover

(Megahan, 1980; Fifield and Harding, 1992; S. Boyce, oral communication)

vi. leaving large tracts of formerly vegetated soil bare leads to a greatly increased erosion rate

* reduced evapotranspiration causes increased short term surface flow

* uncovered land has high erosion potential (Fifield and Harding, 1992)

(Dunne and Leopold, 1978)

2. Water temperature

a. increased by the removal of streamside vegetation

i. clearcutting streamside trees caused a 7° - 8° C mean monthly temperature rise (Montgomery, 1976)

3. Alteration of stream channel

a. Heavy deposition of sediment into stream

i. tractor logging in Redwood Creek, California caused enough sedimentation to cause 10 ′ channel aggradation (Janda et al., 1975)

ii. combination of steep slopes, heavy rains, and erodible soils can generate conditions such that active gullying takes place een when initial logging stimulus is removed (Dunne and Leopold, 1978)

b. loss of historical woody vegetation inputs

c. streams draing areas disturbed by logging have fewer debris dams and less organic matter accumulation than streams draining undisturbed sites (Golladay *et al.*, 1987)

4. Impacts on aquatic food supply

a. lethal effects of sedimentation

b. loss of organic input which forms basis of aquatic food webs (Budd et al., 1987)

5. Streamside buffer strips

a. sediment

i. vegetation along stream banks holds soil in place, prevents instream erosion, and stabilizes the channel (Budd et al., 1987)

* some investigators feel that water velocity on steep slopes is too great to allow significant filtration of sediment (Palfrey and Bradley, 1982; G. Wood, oral communication)

* other authors recommend using vegetated filter strips on slopes > 40% (Budd *et al.*, 1987)

* if the retention capacity of streamside filter strips along steep slopes is reduced, then effective erosion and sedimentation control measures must be practiced on entire watershed

ii. when 98.4 ' buffers were used in study, <u>no sedimentation</u> was measured in stream (Erman et al., 1977)

iii. some investigators believe that on steep terrain the filtering capacity of vegetated strips is not very high (Phillips, 1989; G. Wood, oral communication)

    * should then protect forest floor integrity on entire watershed

b. stream structure

i. removal of woody debris after logging stripped the stream of necessary woody material needede for structure (Bisson and Sedel, 1982)

ii. most woody debris in streams is from forested areas located within 100' of banks (Budd et al., 1987)

c. aquatic organisms

i. over 99% of energy and hydrocarbons in aquatic food webs originated from adjacent forest ecosystems (Budd et al., 1987)

ii. again, most of this organic matter is from forests within 100' of stream (Budd et al., 1987)

iii. when buffers in one study were less than 98.4' (30 m), the stream sediment caused a change in the aquatic insect life that formed the basis of fish diets (Erman et al., 1977)

iv. food supply of benthic organisms was unaffected when buffers of at least 98.4′ were used during and after logging (Erman et al., 1977)

v. streams with buffers < 98.4′ were impacted by logging activities (logging roads in this study were considered to have a negligible effect)

vi. streams draining logged areas with buffer strips > 98.4′ had no measurable effect on the macrobenthos

(Newbold *et al.*, 1980)

d. water temperature

i. vegetation canopy

* blocks solar radiation in summer and moderates temperature extremes

* blocks wind and air flow, helping to insulate and keep streams from low temperature extremes in winter

(Budd et al., 1987)

* patch cut watershed with buffers exhibited no increase in temperature attributable to logging

* clearcut watersheds had a monthly mean maximum increase of 7° - 8° C

(Montgomery, 1976)

* filters sediment which can slow the warming and cooling processes of the water (Ellis, 1936)

e. wildlife habitat

i. streamside habitats extend at least 90′ beyond banks of streams (Washington Dept. of Ecology, 1981)

6. Recommendations

a. avoid activities that would disturb the forest floor cover

i. no more than 65% of the watershed should be unvegetated at any time, including all mined, row cropped, and road areas

  * this will allow the site's erosion control efficiency to be approximately 92% (Harding and Fifield, unpublished)

ii. follow SCS recommendations for Jackson County and cabel or helicopter log all sites with a soil erosion potential rating of "severe."

iii. follow SCS recommendations and do not use wheeled vehicles on soils with erosion control rating of "moderate" or "severe"

iv. **maintain forest floor integrity**

  * allow leaf litter and logging debris to remain in the ground

  * avoid site prep practices

    - especially avoid mechanized site prep

    - if site prep is insisted upon, only the cut and fell method (where cut logs are either left in place, sky yarded out, or skidded out with a minimum of skid roads and land disturbance) is recommended, unless <u>specifically</u> managing for the endangered red-cockaded woodpecker's longleaf pine habitat

    - if prep burns are used, they must be followed immediately (< X hours) by seeding/planting and mulching (which must be completed within Y hours of the burn)

    - herbicides would disturb the forest floor to a far lesser degree than other site prep practices (mechanized, burning), but

* freshwater mussels can accumulate organic toxins in concentrations *thousands of times greater* than the concentration in the surrounding water (Fikes and Tubb, 1971)

* present tremendous negative impacts to threatened and endangered mussel species of Horse Lick Creek

* organic toxin (DDT) application in Vancouver Island subject to the following restrictions:

  - not using streams as boundaries of treatment areas so the streams would not be subject to a double dose of spray

  - pesticide sprayed parallel to major streams, but at least one swath away

  - spray was shut off when streams were crossed

* despite these precautions, the coho salmon fry mortality was nearly 100% in four major streams

* pesticides reach streams by surface runoff, not just direct application

(Rudd, 1964)

* as long as forest floor integrity is maintained, surface runoff appears to

be negligible in eastern forests (Patric, 1976)

- so perhaps if an **undisturbed** (and unsprayed) 100' buffer strip is left along perrenial and intermittents streams, the herbicide transport via surface runoff would be negligible, and herbicides could be "safely" used

* intensively use cabel logging system to reduce number of skid trails

* mulch and seed/plant any ground that has been disturbed

  - if using natural regeneration, consider just leaving leaf litter and logging debris intact and allow natural regeneration to take place

b. maintain **undisturbed streamside buffers** of at least 100' on each side of perennial and intermittent streams

  i. on stream sites adjacent to agricultural areas, increase with to 150' but allow cabel logging on outer 50' to aid in continual nutrient uptake by regenerating vegetation

  ii. avoid disturbing the bottom of ephemeral streams; these streams carry large sediment loads to perennial streams during storm events (NCDFR, 1989)

References

Arruda, J. A., G. A. Marzolf, and R. T. Faulk. 1983. The role of suspended sediments in the nutrition of zooplankton in turbid reservoirs. *Ecology* **64**(5):1225-1235.

Ahlstedt, S. A. 1986. A status survey of the little-wing pearly mussel (*Pegias fabula*) (Lea 1838). Report submitted in fulfillment of U.S. Fish and Wildlife Service Contract No. 14-16-0004-840927. 38 pp.

Baker, F. C. 1922. The molluscan fauna of the Big Vermillion River, with special reference to its modification a s aresult of pollution by sewage and manufacuring wastes. *IL Biol. Monogr.* **7**(2):1-126.

Bedford, J. W., E. W. Roelefs, and M. J. Zabik. 1968. The freshwater mussel as a biological monitor of pesticide concentrations in a lotic environment. *Limnol. Oceanogr.* **13**:118-126.

Branson, B. A. and D. L. Batch. 1972. Effects of strip mining on small stream fishes in east-central Kentucky. *Proc. of Biol. Soc. Wash.* **84**(59):507-518.

Bisson, P. A. and J. A. Sedell. 1982. Salmonid populations in the streams in clearcut vs old-growth forests of western Washington. Weyerhauser Company, Tacoma, WA. 17 pp.

Budd, William W., Paul L. Cohen, Paul R. Saunders, and Frederic R. Steiner. 1987. Stream corridor management in the Pacific Northwest: I. Determination of stream-corridor widths. *Env. Mangt.* **11**(5):587-597.

Churchill, E. P. Jr. and S. I. Lewis. 1924. Food and feeding in freshwater mussels. *Bull. Bureau Fish.* **39**:439-471.

Dennis, Sally D. 1984. Distributional Analysis of the Freshwater Mussel Fauna of the Tennessee River System, with Special Reference to Possible Limiting Effects of Siltation. Doctoral dissertation. Virginia Polytechnic Institute and State University. Blacksburg, Virginia. 247 pp.

Dillaha, T. A., J. H. Sherrard, D. Lee, S. Mostaghimi, and V. O. Stanholtz. 1985. Sediment and phosphorus transport in vegetative filter strips: Phase I, field studies. *Am. Soc. of Agr. Eng.*, Paper 85-2043.

DiStefano, Robert J. 1984. Freshwater mussels (Bivalvia: Unionidae) of Horse Lick Creek, Rockcastle River, Kentucky. *The*

Nautilus 98(3):110-3.

Douglass, James E. and Wayne T. Swank. 1975. Effects of management practices on water quality and quantitiy: Coweeta Hydrologic Laboratory, North Carolina. *USDA For. Ser. Gen. Tech. Rep., NE-13*. pp. 1-13.

Dunne, Thomas and Luna B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman and Company, New York. 818 pp.

Ellis, M. M. 1931. Some factors affecting the replacement of the commercial fresh-water mussels. *U.S. Bureau of Fisheries Circular 7*.

\- 1936. Erosion silt as a factor in aquatic environments. *Ecology* 17:29-42.

Erman, Don C., J. D. Newbold, and K. B. Roby. 1977. Evaluation of streamside buffer strips for protecting aquatic organisms. California Water Resources Center, Univ. of Cal., Davis. 48 pp.

Fikes, M. H. and R. A. Tubb. 1971. *Amblema plicata* as a pesticide monitor. pp. 34-37. IN: Rare and Endangered Mollusks (Naiads) of the U.S. U.S. Fish and Wildlife Service, Twin Cities, Minnesota.

Fuller, Samuel L. H. 1974. Clams and mussels (Mollusca:Bivalvia). pp. 215-273. IN: Pollution Ecology of Freshwater Invertebrates. C. W. Hart, Jr. and Samuel L. H. Fuller (eds.). Academic Press. New York.

Fuller, S. 1977. Freshwater and terrestrial mollusks. pp. 143-194. IN: J. E. Cooper, S. S. Robinson, and J. B. Funderburg (eds.). Endangered and Threatened Plants and Animals of North Carolina. North Carolina State Museum of Natural History, Raleigh.

Golladay, S. W., J. R. Webster, and E. F. Benfield. 1987. Changes in stream morphology and storm transport of seston following watershed disturbance. *J. N. Am. Benthol. Soc.* 6(1):1-11.

Grantham, B. J. 1969. The fresh-water pelecypod fauna of Mississippi. Doctoral dissertation. University of Southern Mississippi. Hattiesburg, Mississippi. 243 pp.

Harding, Michael V. and Jerald S. Fifield. 1992. Practical Approaches for Effective Erosion and Sediment Control. Unpublished course book for the International Erosion Control Association.

Hobden, D. J. 1970. The catalase of a freshwater bivalve. *Can. J. Zool.* 48:201-203.

Horne, Francis R. and Steven McIntosh. 1979. Factors influencing distributtion of mussels on the Blanco River of Central Texas. *The*

Nautilus. **94**(4):119-133.

HydroDynamics Incorporated. 1991. Douglas County Storm Drainage Design and Technical Criteria, Addendum A, Erosion Control Criteria - Draft. HydrDynamics Incorporated, Parker, Colorado. 64 pp.

Imlay, M. J. 1971. Bioassay tests with naiads. pp. 38-41. IN: Rare and Endangered Mollusks (Naiads) of the U.S. U.S. Fish and Wildlife Service, Twin Cities, Minnesota.

Jacobs, T. C. and J. W. Gilliam. 1985. Headwater stream losses of nitrogen from two coastal plain watersheds. *J. Env. Qual.* **14**(4):467-472.

Janda, R. J., M. K. Nolan, D. R. Harden, and S. M. Colman. 1975. Watershed conditions in the drainage basin of Redwood Creek, Humboldt Co., California, as of 1973. U S Geological Survey Open File Report no. 75.568, 260 pp.

Johnson, C. W. and J. P. Smith. 1983. Soil Loss Caused by Off-road Vehicle Use on Steep Slopes. Presented to the 1981 Winter Meeting of the Am. Soc. Agr. Eng. 16 pp.

Johnson, R. I. 1980. Zoogeography of North American Unionacea (Mollusca:Bivalvia) North of the maximum Pleistocene glaciation. *Bull. Mus. Comp. Zool.* **149**(2):189 pp.

Jorgensen, C. B. 1975. Comparative physiology of suspension feeding. *An. Rev. Phys.* **37**:57-79.

Layzer, James B. and Robert M. Anderson. 1992. Impacts of the Coal Industry on Rare and Endangered Aquatic Organisms of the Upper Cumberland River Basin. Tennessee Cooperative Fishery Research Unit. Cookeville, TN. 118 pp.

Leopold, L. B. and T. M. Maddock. 1954. The Flood Control Controversy: Big dams, Little dams, and Land Management. Ronald Press, New York. 278 pp.

Loar, J. M., L. L. Dye, R. R. Turner, and S. G. Hildebrand. 1980. Analysis of environmental issues related to small-scale hydroelectric development: 1. Dredging. ORNL, Env. Science Div. Publ. No. 1565, Oak Ridge, TN. 134 pp.

Loosanoff, V. L. 1961. Effects of turbidity on some larval and adult bivalves. Gulf Caribb. Fish. Inst. Univ. Miami Proc. **14**:80-95.

Lowrance, R., R. Todd, J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, and L. Asmussen. 1983. Riparian forests as nutrient filters in agricultural watersheds [Agriculture fertilizer runoff control, Georgia]. *Bioscience* **34**(6):374-377.

Lowrance, R. R., R. L. Todd, and L. E. Asmussen. 1984. Nutrient cycling in an agricultural watershed: I. Phreatic movement. *J. Env. Qual.* 13(1):22-27.

Lull, H. W. 1965. Factors influencing water production from forested watersheds. p. 2-7 IN: Proceedings of the Municipal Watershed Management Symposium. Amherst, Mass. Univ. Mass., Pub. 446.

Magette, W. L., R. B. Brinsfield, R. E. Palmer, J. D. Wood, T. A. Dillaha, and R. B. Reneau. 1987. Vegetated Filter Strips for Agricultural Runoff Treatment. USEPA Region III, CBP/TRS 2/87.

Magette, W. L., R. B. Brinsfield, R. E. Palmer, and J. D. Wood. 1989. Nutrient and sediment removal by vegetated filter strips. *Am. Soc. Agr. Eng.* 32(2):336-337.

Matter, William J. and John J. Ney. 1981. The impact of surface mine reclamation on headwater streams in southwest Virginia. *Hydrobiologia* 78:63-71.

Matteson, M. R. 1955. Studies on the natural history of the Unionidae. *Amer. Midl. Natur.* 53:126-145.

Meade, R. H. 1969. Errors in using modern stream-load data to estimate natural rates of denudation. *Geol. Soc. Am. Bull.* 80:1265-1274.

Megahan, Walter F. 1982. Effects of the silvicultural practices on erosion and sedimentation in the interior west- A case for sediment budgeting. p. 169-181 IN: Proceed. Sympos. Interior West Watershed Management. Spokane.

Miller, C. W., B. M. Zuckerman, and A. J. Charig. 1966. Water translocation of diazinon-C^{14} and parathion-S^{35} off a model cranberry bog and subsequent occurrence in fish and mussels. *Trans. Amer. Fish. Soc.* 95:345-349.

Montgomery, James M., Consulting Engineers, Inc. 1976. Forest harvest, residue treatment, reforestation, and protection of water quality. Prepared for the U.S. Environmental Protection Agency, National Technical Information Service, Springfield, VA. 273 pp.

Mullican, H. N., R. M. Sinclair, and B. G. Isom. 1960. Survey of the aquatic biota of the Nolichucky River in the state of Tennessee. Tenn. Stream. Pollut. Contr. Bull. Nashville. 28 pp.

Neves, Richard J. and Micheal C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. *J. Wildl. Mngt.* 53(4):934-941.

Newbold, J. D., D. C. Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Can. J. Fish. Aquat. Sci.* 37:1076-1085.

North Carolina Division of Forest Resources. 1989. Forestry Best Management Practices Manual. Department of Environment, Health, and Natural Resources. 67 pp.

Omernik, J. M., A. R. Abernathy, and L. M. Male. 1981. Stream nutrient levels and proximity of agricultural and forest land to streams: Some relationships. *J. of Soil and Water Cons.* **36**(4):227-231.

Palfrey, R. and E. Bradley. 1982. The Buffer Area Study. Coastal Resources Division, Maryland Dept. Nat. Res., Tidewater, MD.

Patric, J. H. 1976. Soil erosion in the eastern forest. *J. of For.* **74**:671-677.

Phillips, J. D. 1989. An evaluation of the factors determining the effectiveness of water quality buffer zones. *J. Hyd.* **107**:133-145.

Rudd, R. L. 1964. Pesticides and the Living Landscape. Univ. of Wisconsin Press, Madison. 320 pp.

Ruffner, Joseph D. 1978. Plant materials on surface-mine reclamation. USDA Soil Conservation Service. Washington, D.C.

Soil Conservation Service. 1978. Rural Abandoned Mine Program. Soil Conservation Service. Washington, D.C. 111 pp.

Soil Conservation Service. 1989. Soil Survey of Jackson and Owsley Counties, Kentucky. 121 pp.

Stansbery, D. H. 1964. The mussel (muscle) shoals of the Tennessee River revisited. *Annu. Rep. 1964. Amer. Malacolog. Un.* 25-28.

Stansbery, D. H. 1967. Growth and longevity of naiads from from Fishery Bay in western Lake Erie. *Annu. Rep. 1967 Amer. Malacolog. Un.* 10-11.

Stansbery, D. H. 1969. Changes in the naiad fauna of the Cumberland Falls in eastern Kentucky. *Annu. Rep. 1969 Amer. Malacolog. Un.* 16-17.

Stansbery, D. H. 1970. A study of the growth rate and longevity of the naiad *Amblema plicata* (Say, 1817) in Lake Erie (Bivalvia:Unionidae). *Annu. Rep. 1970 Amer. Malacolg. Un.* 78-79.

Stansbery, D. H. 1973. A preliminary report on the naiad fauna of the Clinch River in the southern Appalachian mountains of Virginia and Tennessee (Mollusca: Bivalvia: Unionidae). *Am. Malacol. Un. Bull.* **1972**:20-22.

Starrett, W. C. 1971. A survey of the mussels (Unionacea) of the Illinois River: A polluted stream. *Ill. Natur. Hist. Surv. Bull.* 30:265-403.

Stein, Carol B. 1971. Naiad life cycles: The significance in the conservation of the fauna. pp. 19-28. IN: Rare and Endangered Mollusks (Naiads) of the U.S. U. S. Fish and Wildlife Service, Twin Cities, Minnesota.

U.S. Fish and Wildlife Service. 1984. Cumberland Bean Pearly Mussel Recovery Plan. U.S. Fish and Wildlife Service. Atlanta, Georgia. 58 pp.

U.S. Fish and Wildlife Service. 1988. Endangered and Threatened Species of the Southeastern United States. U.S. Fish and Wildlife Service. Atlanta, Georgia.

U.S. Fish and Wildlife Service. 1989. Little-wing Pearly Mussel Recovery Plan. U.S. Fish and Wildlife Service. Atlanta, Georgia. 29pp.

van der Schalie, H. 1938. The naiad fauna of the Huron River in Southeastern Michigan. Univ. of Mich. Press, Ann Arbor, MI.

Washington Department of Ecology. 1981. Western Washington urban stream assessment. Washington Dept. of Ecol., Office of Water Prog., Water Qualtiy Planning. Olympia, WA. 54 pp.

Washington State Forest Practices Technical Advisory Committee. 1979. Forest Practice Demonstration Project: Logging Slash and Debris. Submitted by the Task LSD Subcommittee, Olympia, WA. 38 pp.

Wilson, C. B. and H. W. Clark. 1914. The mussels of the Cumberland River and its tributaries. Rep. U.S. Comm. Fish. for 1912 and Spec. Papers. Separately issued as Bur. Fish. Document No. 781. 63 pp.

Winter, J. E. 1975. Feeding experiments with *Mytilis edulis* L. at small laboratory scale. 10th European Symposium in Marine Biology, Ostend, Belgum. 1:583-600.

Wolcott, Lisa T. 1990. Coal Waste Deposition and the Distribution of Freshwater Mussels in the Powell River, Virginia. Masters' Thesis. Virginia Polytechnic Institute and State University. Blacksburg, VA. 115 pp.

Wurtz, C. B. 1962. Zinc effects of fresh-water molluscs. *The Nautilus* 76:53-61.

Ziemer, R. R., J. Lewis, R. M. Rice, and T. E. Lisle. 1991. Modeling the cumulative watershed effects of forest management strategies. *J. Env. Qual.* 20:36-42.

Zon, R. 1927. Forests and water in the light of scientific investigation. U.S. National Waterways Commission, Final Report Appendix V:205-302, 62nd Congress, Seconf Session, Senate Document 469.

Please give me a copy. DOD

; File

TO: Mike Lipford, VAFO/Clinch Valley
~~Bill~~ Kittrell, Clinch Valley

FROM: Jacqueline Mohan, SERO

Date: January 27, 1995

re: Freshwater mussel/Horse Lick Creek stress analysis

I recently re-located the enclosed document, *Analysis of Freshwater Mussel Stresses: Stress Effects, Sources and Mitigation* and thought some of the information might be useful to to the Clinch Valley project. Although this was written through my work on the Horse Lick Creek Bioreserve and site design in the Southeast Regional Office, the information contained applies in general to freshwater mussels and, as filter-feeding bivalves are good indicators of aquatic integrity, to aquatic communities.

I hope this might prove useful to you! Thank you.